

## Summary of ARINC's Broadband Over Power Lines Modeling and Interference Analysis

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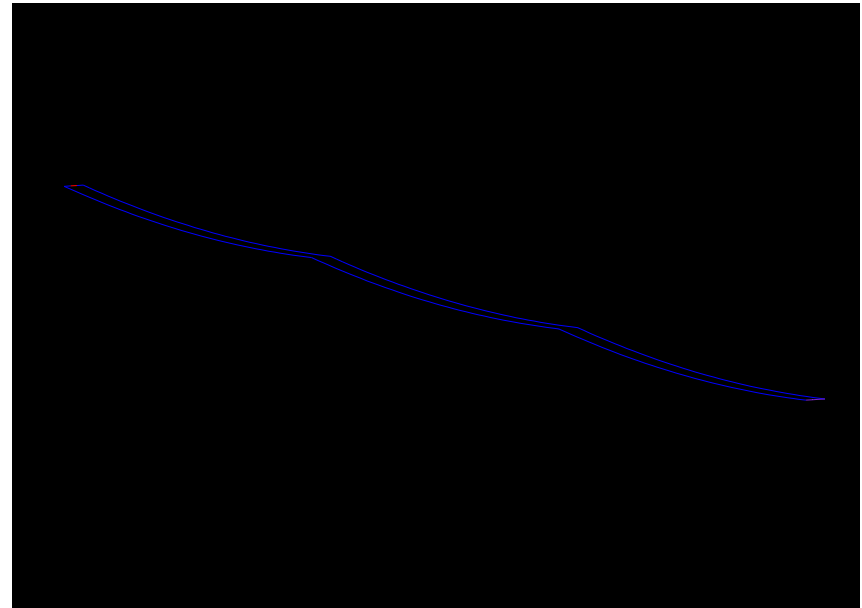


# ARINC BPL Modeling

- This model attempts to predict the interfering signal strengths presented at various distances from a single BPL radiator at a fixed height above ground of 100 [ft] in the frequency range of 3 – to 20 MHz.
- Modeling software: method-of-moments analysis program Numerical Electromagnetic\_Code, Version 4.1 (NEC),

# ARINC BPL Modeling Parameters

- Parameters
  - 2000 ft span 12 sections 3 ft sag (figure depicts only 3 sections)
  - $Z_{load} = R + j0$ 
    - $R = 6.25, 12.5, 25, 50, 100, 200, 400, 1000$
  - $P_{input} = 1\text{mW}$
  - Excitation voltage was varied with input impedance to produce 1mW input power.
  - 6 ft spacing between parallel sections
  - 40ft above ground
  - Differentially Fed Excitation
  - Used Avg Ground parameters (conductivity=.005 dielectric = 13)
  - Analyzed  $f = 3, 5, 10, 15, 20\text{ Mhz}$



# BPL Analysis Approach

- Assumed horizontally polarized ground side receive antenna.
- Distances analyzed from BPL antenna  $D = 100\text{ft}, 200\text{ft}, 500\text{ft}, 1000\text{ft}, 2000\text{ft}, 1\text{mi}, 2\text{mi}$  and  $5\text{mi}$
- At distances ( $D = y$ ) of  $1000\text{ft}$  and less, the analyses looked at 1000 points between  $-1000\text{ft} = x = 1000\text{ft}$  at a height of  $100\text{ft}$  above ground parallel to the BPL radiator.
- At distances of  $2000\text{ft}$  and greater, the analysis looked at 360 points ( $\phi$ ) around the BPL antenna at a fixed receive antenna height of  $100\text{ft}$ .
- Antenna Height above ground was assumed fixed at ( $z$ ) =  $100\text{ft}$  for all analysis
- $|E|$  near field horizontal signal strength was calculated at each point and sorted for maximum in  $\text{dBuV/m}$
- Far Field pattern was analyzed reporting maximum power gain  $[\text{dBi}]$  and take off angle.

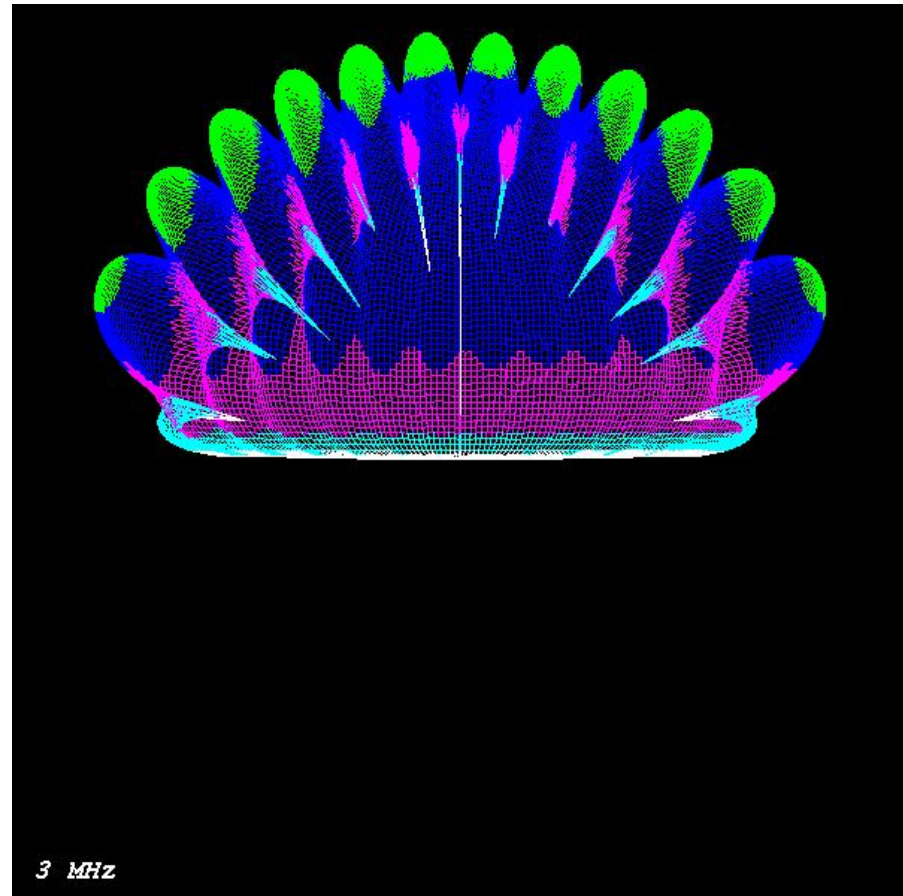


# Radiation Pattern Plots Explained

- Horizontal Gain is Depicted
- Patterns are color coded based on their power gain:



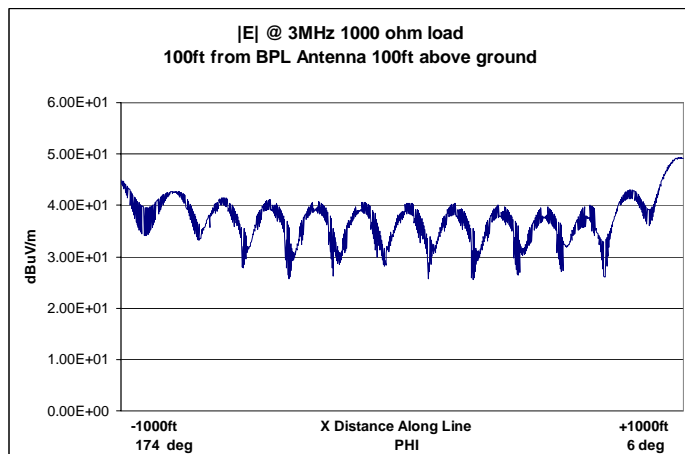
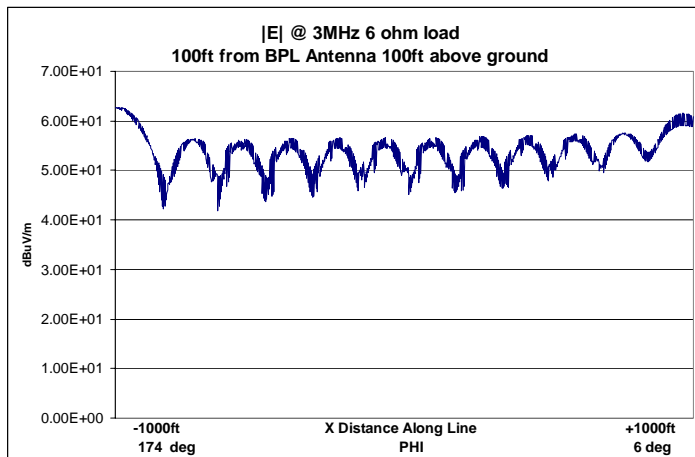
– Red	> 0 dBi
– Yellow	0 to – 10 dBi
– Green	-10 to -20 dBi
– Blue	-20 to -30 dBi
– Magenta	-30 to -40 dBi
– Cyan	-40 to -50 dBi
– White	<-50 dBi



# BPL Power Gain [dBi] Summary

Freq [MHz]	R Load [ohms]	Theta	Phi	MAX Gain dBi		Freq [MHz]	R Load [ohms]	Theta	Phi	MAX Gain dBi
3	6.25	5	0	-7.7		15	6.25	67	0	6
3	12.5	5	0	-9.5		15	12.5	67	1	5.1
3	25	5	0	-11.7		15	25	67	1	3.7
3	50	5	3	-14.2		15	50	67	1	1.8
3	100	5	0	-16.9		15	100	67	0	-0.5
3	200	5	0	-19.7		15	200	67	0	-3
3	400	4	172	-22.2		15	400	67	0	-5.4
3	1000	6	0	-24.1		15	1000	74	52	-5.3
5	6.25	3	0	-4.9		20	6.25	64	142	5.6
5	12.5	3	0	-6.3		20	12.5	64	142	4.9
5	25	3	0	-8.2		20	25	64	142	3.8
5	50	3	0	-10.5		20	50	64	142	2.1
5	100	9	0	-12.9		20	100	61	36	0
5	200	9	0	-15.2		20	200	60	35	-1.6
5	400	4	0	-16.7		20	400	60	35	-2.6
5	1000	4	0	-16.9		20	1000	60	35	-2.5
10	6.25	52	0	1.8						
10	12.5	52	0	0.9						
10	25	57	177	-0.4						
10	50	57	176	-2.3						
10	100	57	176	-4.6						
10	200	57	177	-7.1						
10	400	56	0	-9.6						
10	1000	68	65	-9.5						

# BPL Interference Summary @ 3Mhz



**BPL Input power of 1mW**

**Receive Antenna Fixed Height 100ft**

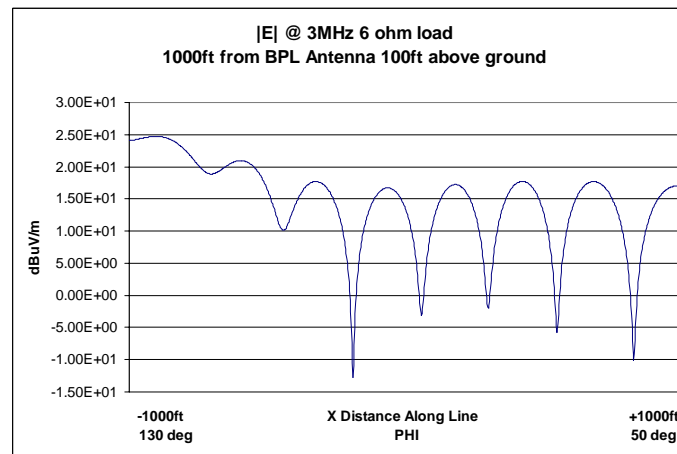
**Maximum predicted interference @ 3MHz 100ft from BPL antenna is 63dBuV/m = 1412.538 uV/m**

**Interference level exhibits 15-20dB swings with various loads**

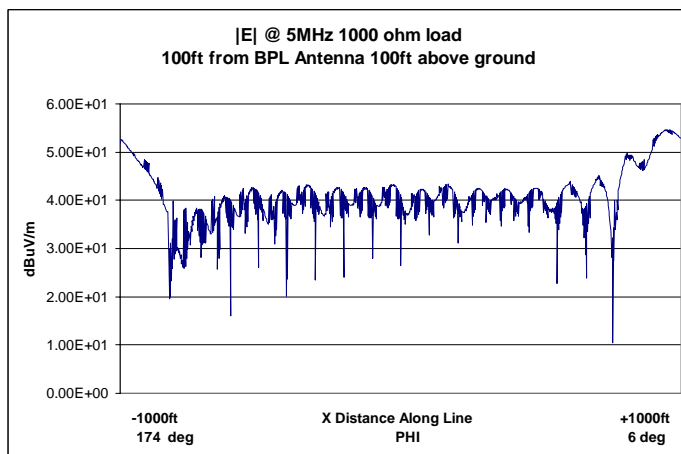
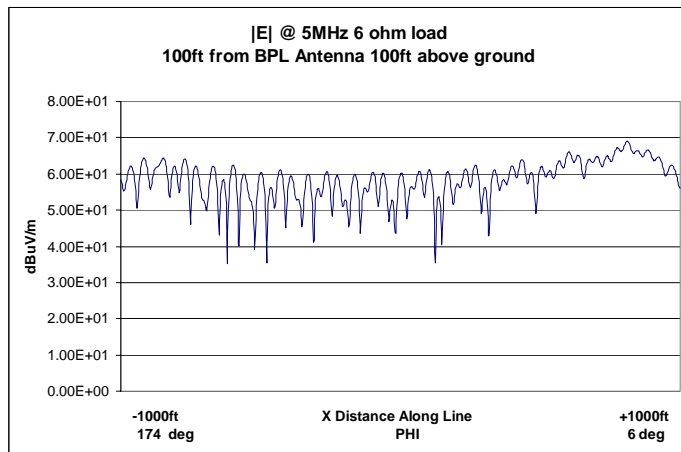
**Highest interference at either end of BPL radiator.**

**Approximate 40dB/decade roll off @ 3MHz**

**Interference will increase from figures below as BPL radiation angle increases. High site installations will be subject to more interference.**



# BPL Interference Summary @ 5Mhz



**BPL Input power of 1mW**

**Receive Antenna Fixed Height 100ft**

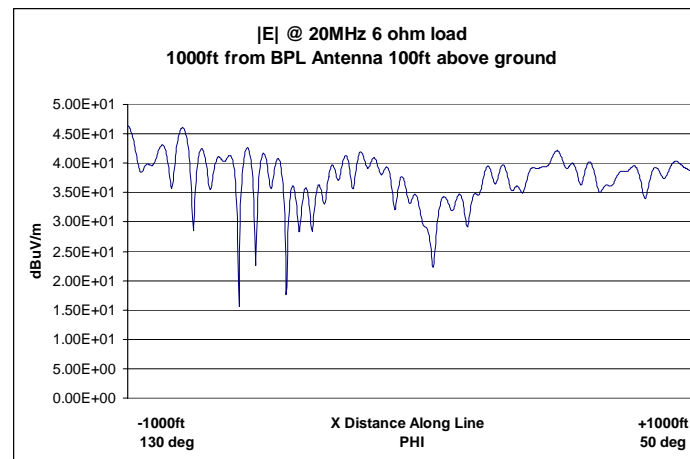
**Maximum predicted interference @ 5MHz 100ft from BPL antenna is 69dBuV/m = 2818.38 uV/m**

**Interference level exhibits 15-20dB swings with various loads**

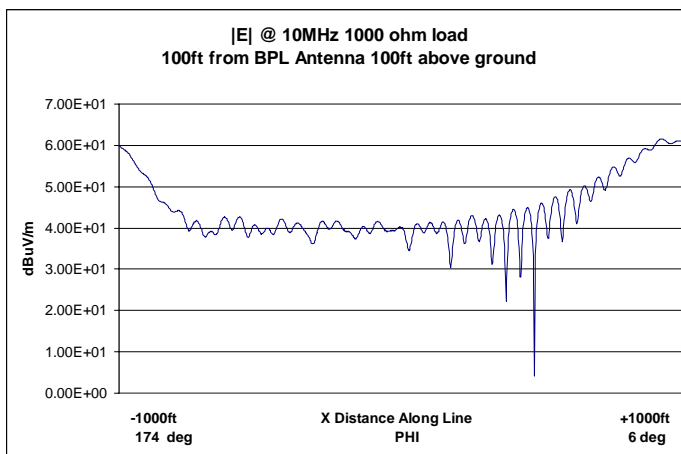
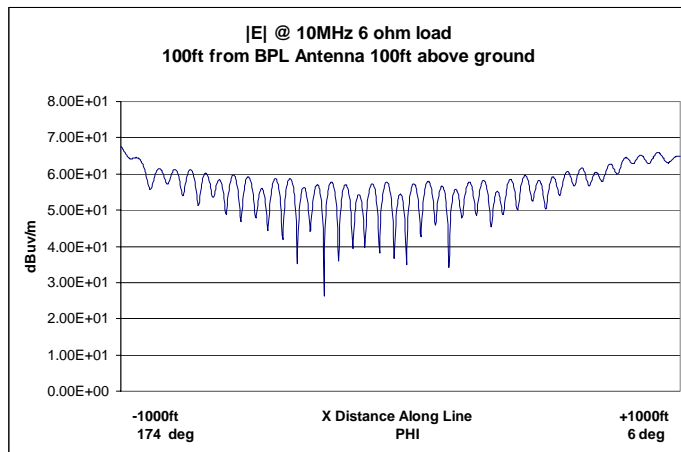
**Highest interference at either end of BPL radiator**

**Approximate 20dB/decade roll off @ 5MHz**

**Interference will increase from figures below as BPL radiation angle increases. High site installations will be subject to more interference.**



# BPL Interference Summary @ 10Mhz



**BPL Input power of 1mW**

**Receive Antenna Fixed Height 100ft**

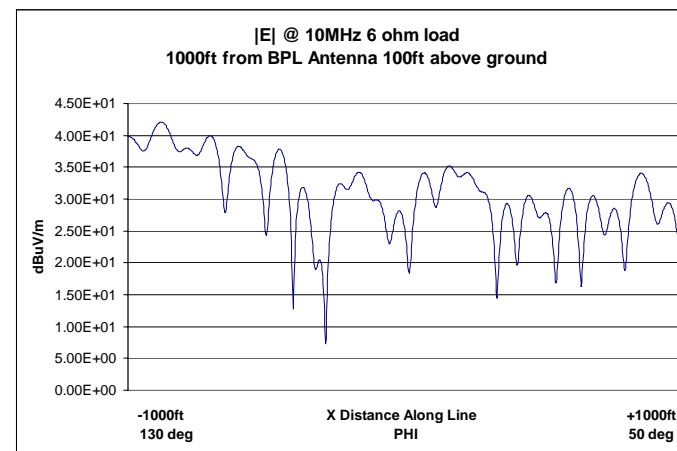
**Maximum predicted interference @ 10 MHz 100ft from BPL antenna is 67.7dBuV/m = 2426.6 uV/m**

**Interference level exhibits approximate 10dB swings with various loads**

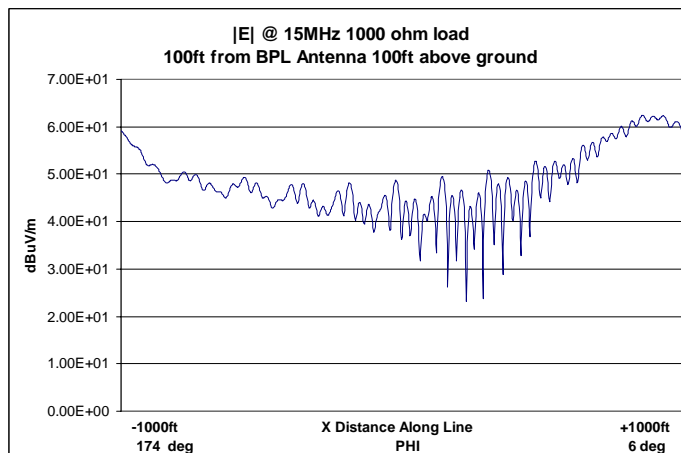
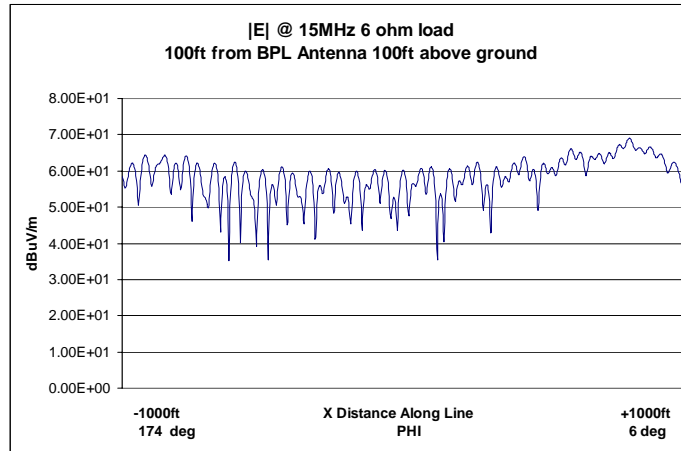
**Highest interference at either end of BPL radiator**

**Approximate 20 dB/decade roll off @ 10MHz**

**Interference will increase from figures below as BPL radiation angle increases. High site installations will be subject to more interference.**



# BPL Interference Summary @ 15Mhz



**BPL Input power of 1mW**

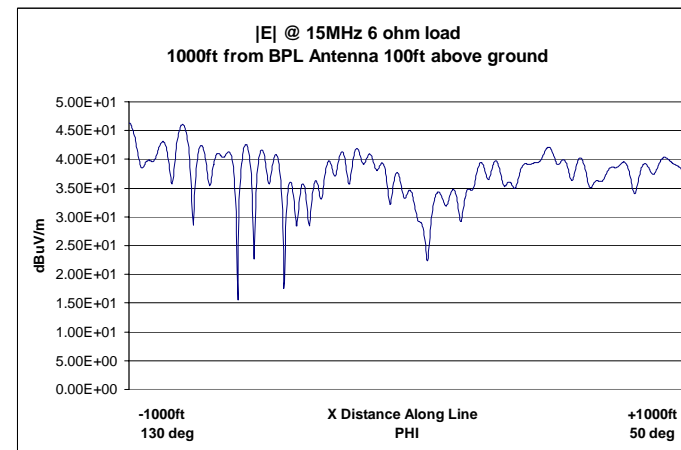
**Receive Antenna Fixed Height 100ft**

**Maximum predicted interference @ 20 MHz 100ft from BPL antenna is 69dBuV/m = 2818.38 uV/m**

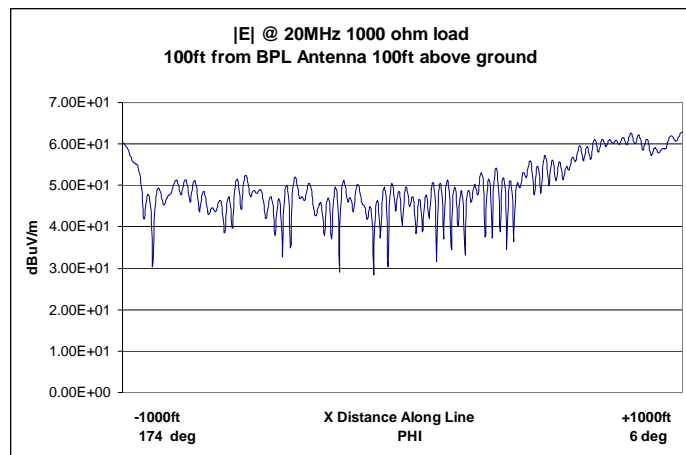
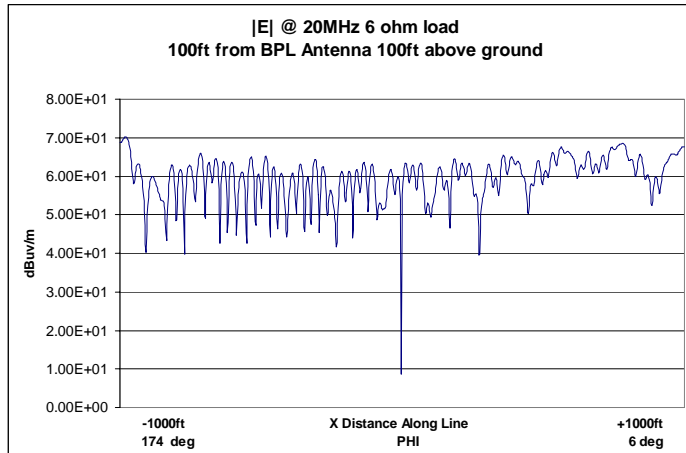
**Interference level exhibits approximate 10dB swings with various loads**

**Highest interference at either end of BPL radiator**

**Approximate 20 dB/decade roll off @ 15MHz Interference will increase from figures below as BPL radiation angle increases. High site installations will be subject to more interference.**



# BPL Interference Summary @ 20Mhz



**BPL Input power of 1mW**

**Receive Antenna Fixed Height 100ft**

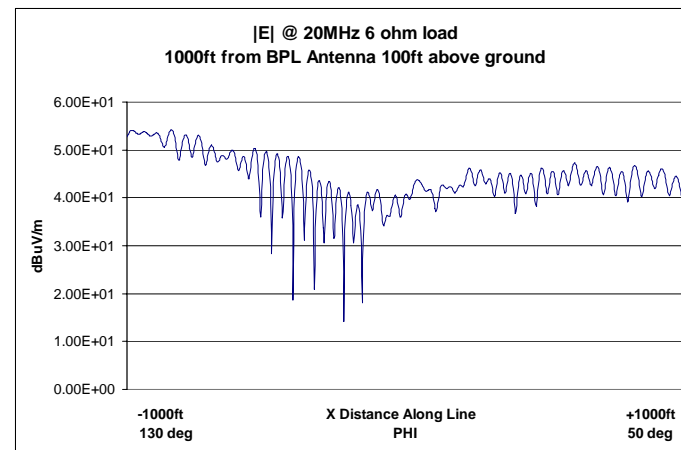
**Maximum predicted interference @ 20 MHz 100ft from BPL antenna is 70.2 dBuV/m = 3235.94 uV/m**

**Interference level exhibits approximate 10dB swings with various loads**

**Highest interference at either end of BPL radiator**

**Approximate 20 dB/decade roll off @ 20MHz**

**Interference will increase from figures below as BPL radiation angle increases. High site installations will be subject to more interference.**



# Conclusions

- The Part 15 40dB/decade factor is over optimistic by approximately +20dB. A more realistic extrapolation factor may be 15 to 20 dB/decade. This assumes you are measuring a point along the radiator which provides a maximum field strength which is highly unlikely.
- The pattern data shows a significant variation in received interference signal level as you move along the radiator. Swings of approximately 30dB or more are typical. It can be concluded that taking a small number of field point measurements (in the near field) and extrapolating to predict signal strengths farther away from the antenna produces a very low degree of confidence in establishing the real received BPL signal strengths.
- Although this simplified model may not represent the BPL system in full, the predictions presented provide estimates that predict significant departures from part 15 30uV/m limits.
- This analysis considered a ground side receive site situated on perfectly flat ground with a receive antenna of 100ft. Real world installations will provide receive sites that have a significantly higher look angle from the BPL noise source than those investigated here. The BPL radiator exhibits it's highest gain at these higher elevation angles. As a result interference to high sites will be even higher than those predicted here.



# Conclusions Continued

- Significant increase in gain is seen off the ends of the BPL radiator. For distances less than 2000 ft in this analysis the receive site was examined parallel to the BPL radiator. An increase in interference level will be observed in installations that fall within this region.
- Multiple BPL radiators were not considered in this analysis. Combined signal strengths from multiple BPL sources could dramatically increase the received interference level.
- Skywave propagation was not considered here, but may be significant depending on ionospheric conditions due to the high angle radiation pattern exhibited by the BPL radiator. Combined signal strengths from multiple BPL sources could dramatically increase the received interference level and should be considered.

# ARINC Comments To Report NTIA 04-413

- Analysis Methodology for Aeronautical Services Volume 1, Section 6.5.3 page 6-9. The methodology established by the NTIA looks specifically at interference to airborne receivers from BPL radiators. Although ARINC is concerned with this interference, a potentially greater impact to the aeronautical service is interference from the BPL radiator to the ground side receiver. Typical ground side parameters including noise floor profiles, and high gain directional and omni-directional receive antennas along with the proximity of the BPL radiator to the ground site warrant concern. The analysis provided by ARINC within attempts to quantify this interference potential.

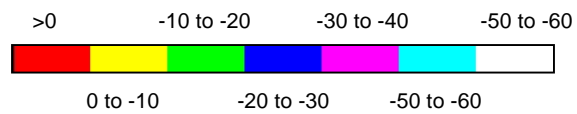
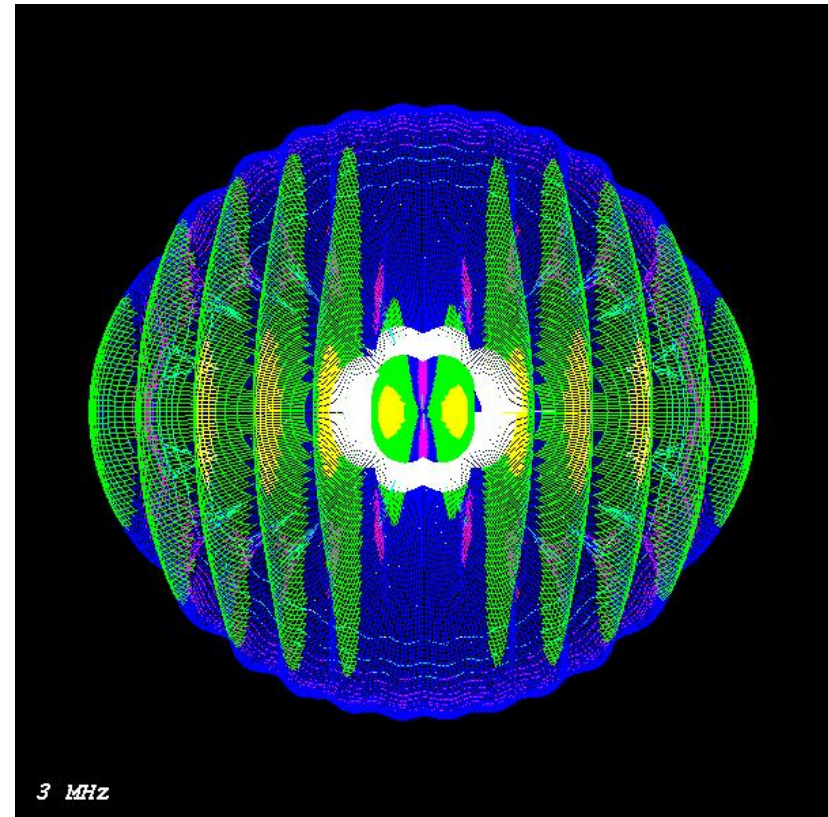
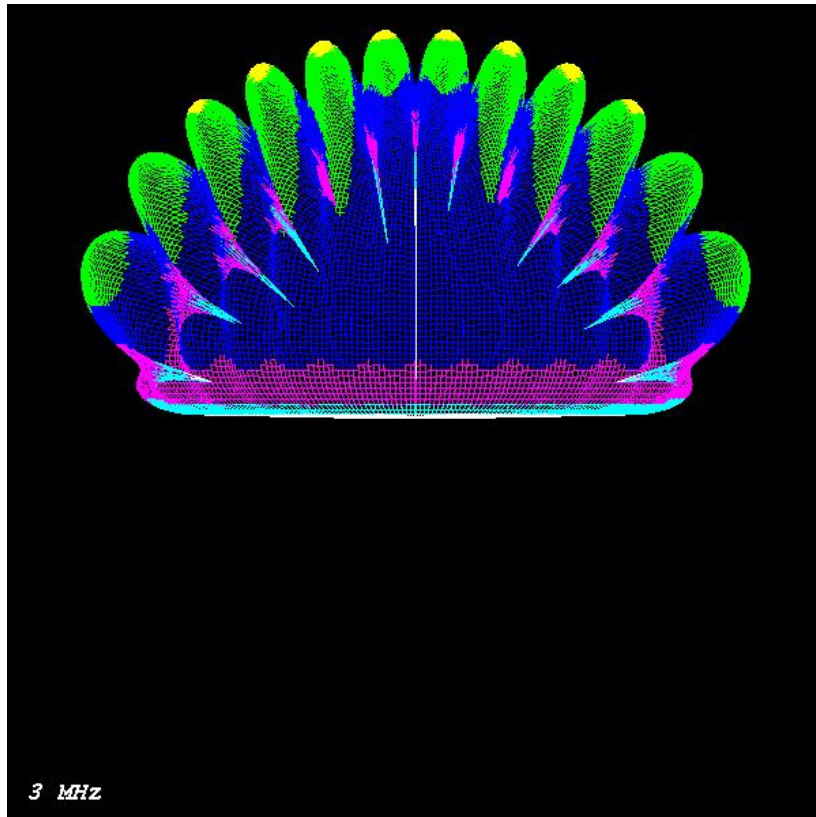
# ARINC Comments To Report NTIA 04-413

- Volume 1, Section 4.5 Table 4-8 pg 4-7 This table incorrectly reports the Aeronautical fixed (ground) antenna gain as 0dBi. ARINC uses a number of both directional and omni-directional HF communication antennas at all of its receive and transmit sites throughout the world. All ARINC HF antennas installed provide greater than 0dBi gain. The gains of the dominant directional and omni directional antennas used by ARINC to provide HF coverage are as follows
  - Directional TCI-527 and 527B min 14.5 – max 18.2dbi gain (front to back ratio of 13dB nominal) 2-30 MHz Tower Ht 220 [ft]
  - Omni-Directional TCI-530 min 5.0 – max 6.5dbi 2-30MHz Tower Ht 101[ft]
  - As a result contributions of the antenna gain values in the predicted interference levels would be underestimated by anywhere from 5dB to 18.2 dB.

# ARINC Comments To Report NTIA 04-413

- Volume 1, Section 6.4 Table 6-2 pg 6-6 This table incorrectly reports the Aeronautical fixed (ground) Noise Environment of “Residential” -111.3 dBW @ 4MHz in a 2.8kHz BW. ARINC receive sites are selected to provide best noise environment possible. A site with a “Residential” noise profile would not be selected by ARINC as a primary receive site candidate. Typical ARINC receive site noise profiles provide a minimum of Quiet RURAL with some approaching REMOTE classification.
  - Using the Noise Power classification established by the NTIA in table 6-1 page 6-5 based on Kansas City Kansas, ARINC believes Aeronautical ground station noise power should be classified at a minimum as Quiet Rural. As a result contributions of the noise floor values in the predicted interference levels would be underestimated by anywhere from 8dB to 15dB.

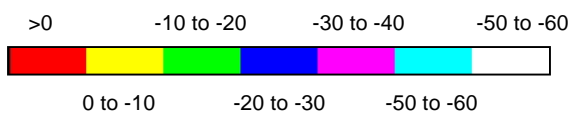
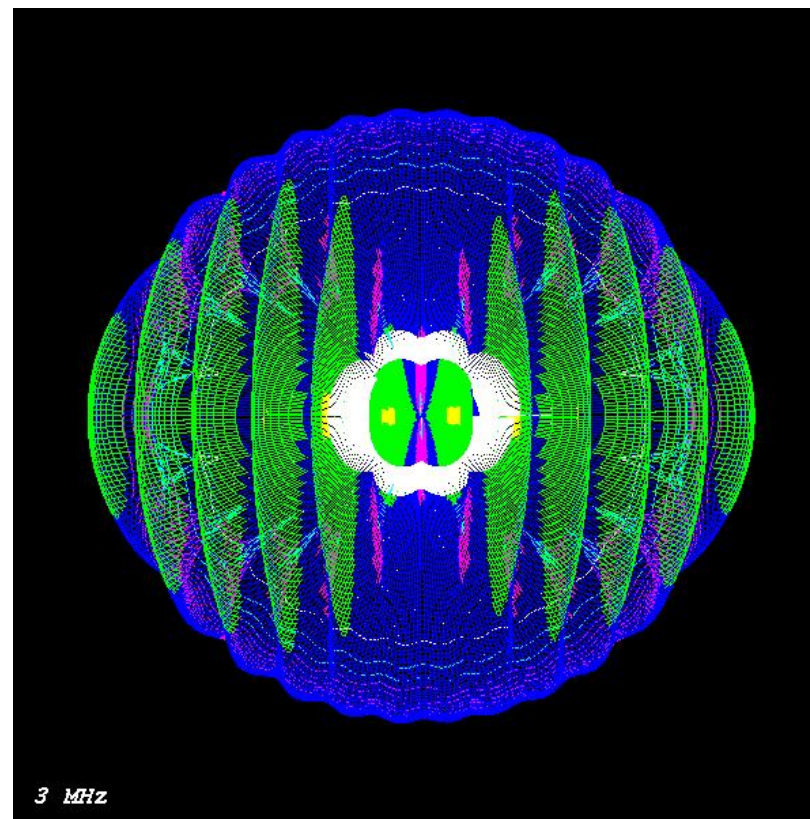
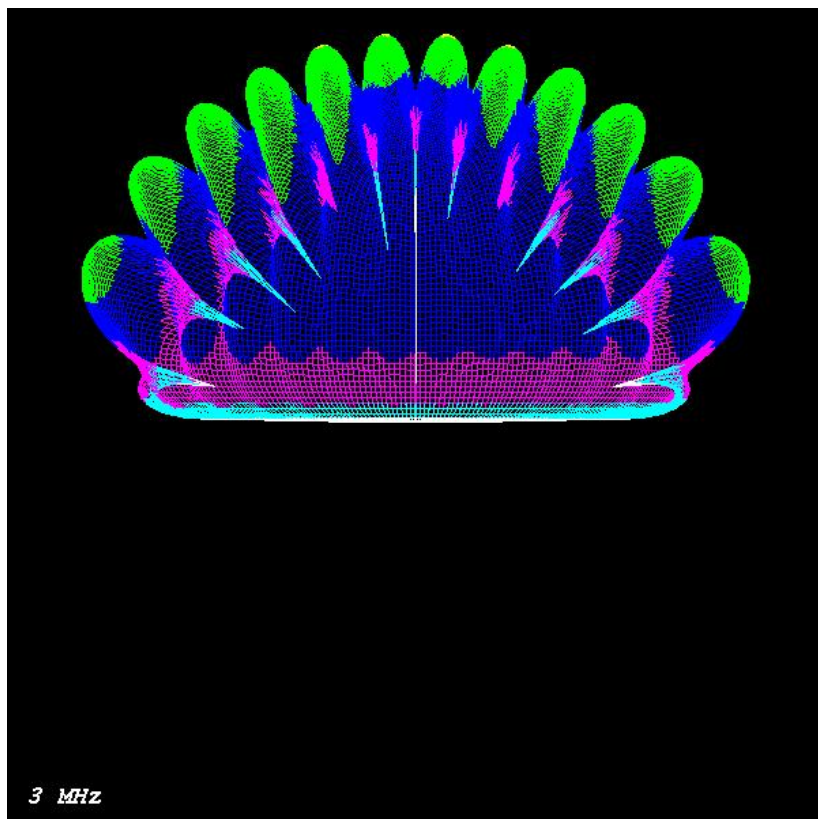
BPL  $Z_{load} = 6.25 + j0$   $Z_{in} = 24 + j577$   $f = 3.0$  MHz



L3M6\_3hpa

L3M6\_3hpb

BPL  $Z_{load} = 12.5 + j0$   $Z_{in} = 37 + j576$   $f = 3.0$  MHz

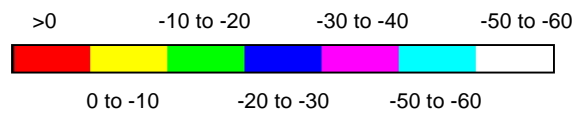
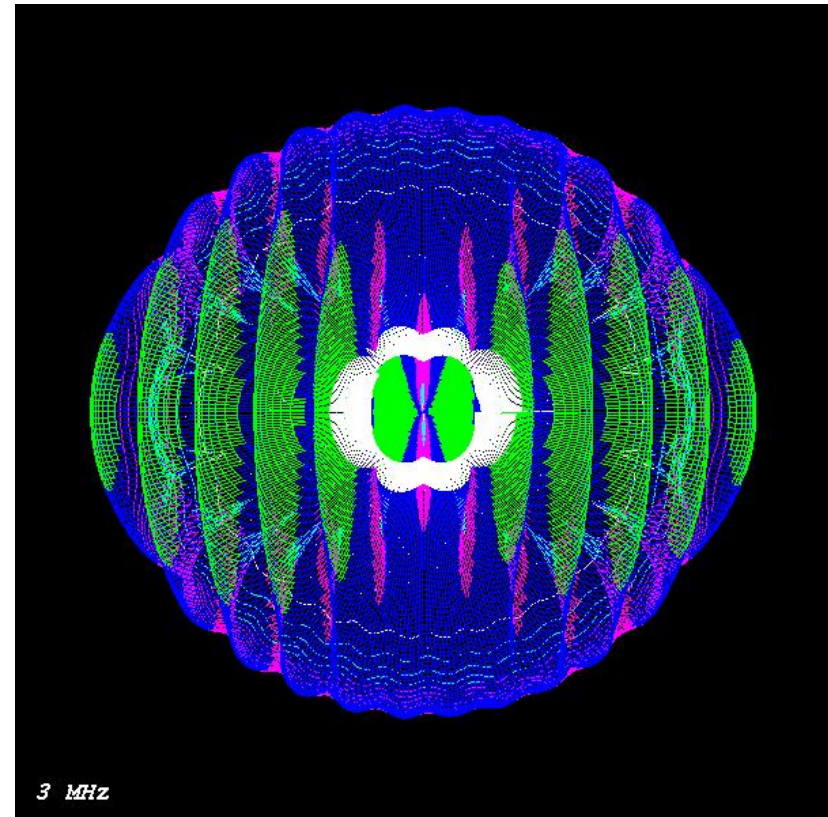
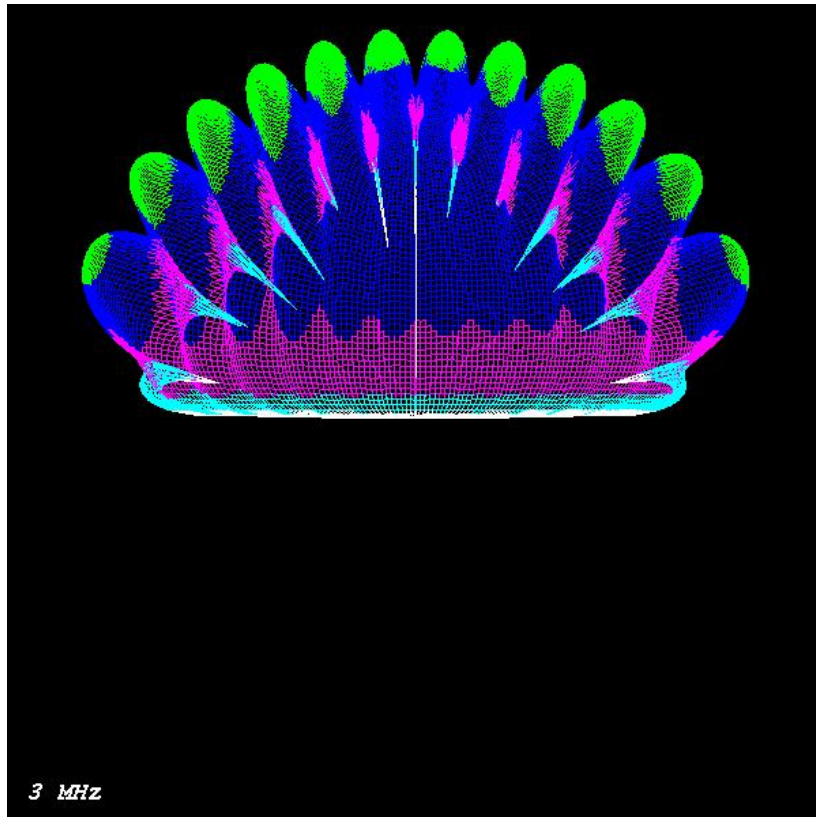


L3M12\_3hpa

L3M12\_3hpb



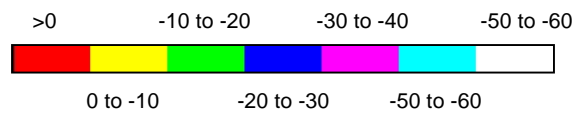
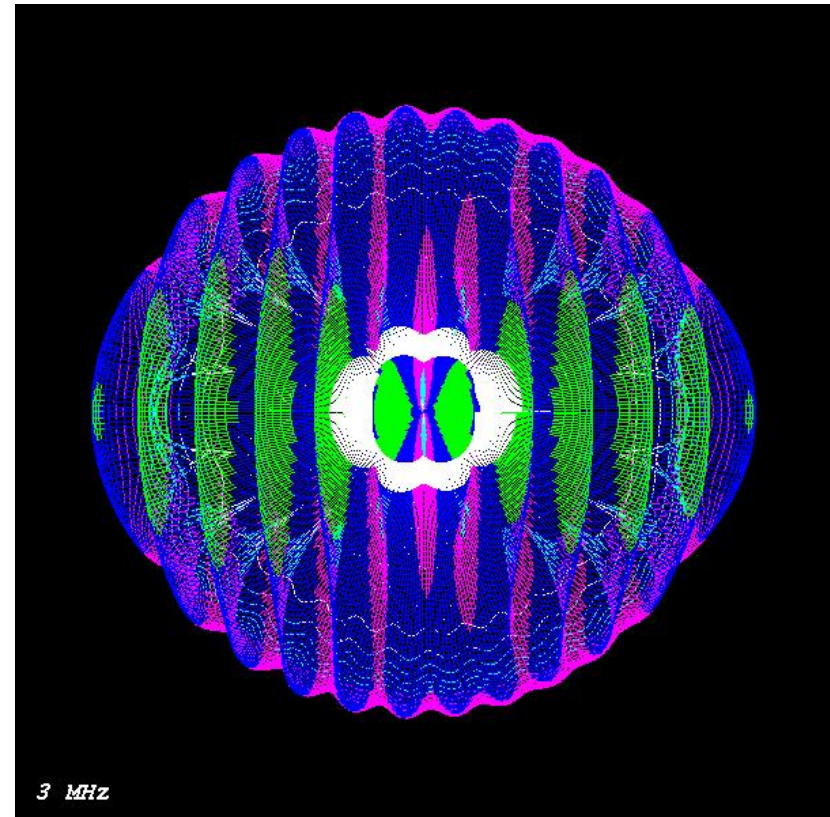
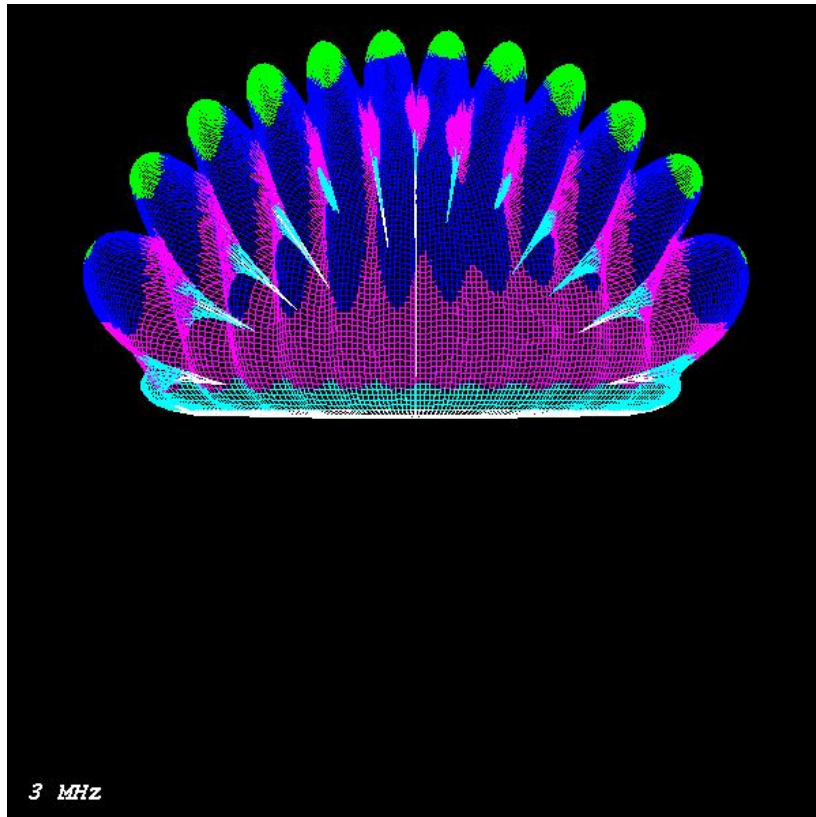
BPL  $Z_{load} = 25 + j0$   $Z_{in} = 61 + j 574$   $f = 3.0$  MHz



L3M25\_3hpa

L3M25\_3hpb

BPL  $Z_{load} = 50 + j0$   $Z_{in} = 109 + j567$   $f = 3.0$  MHz

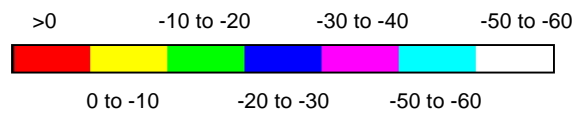
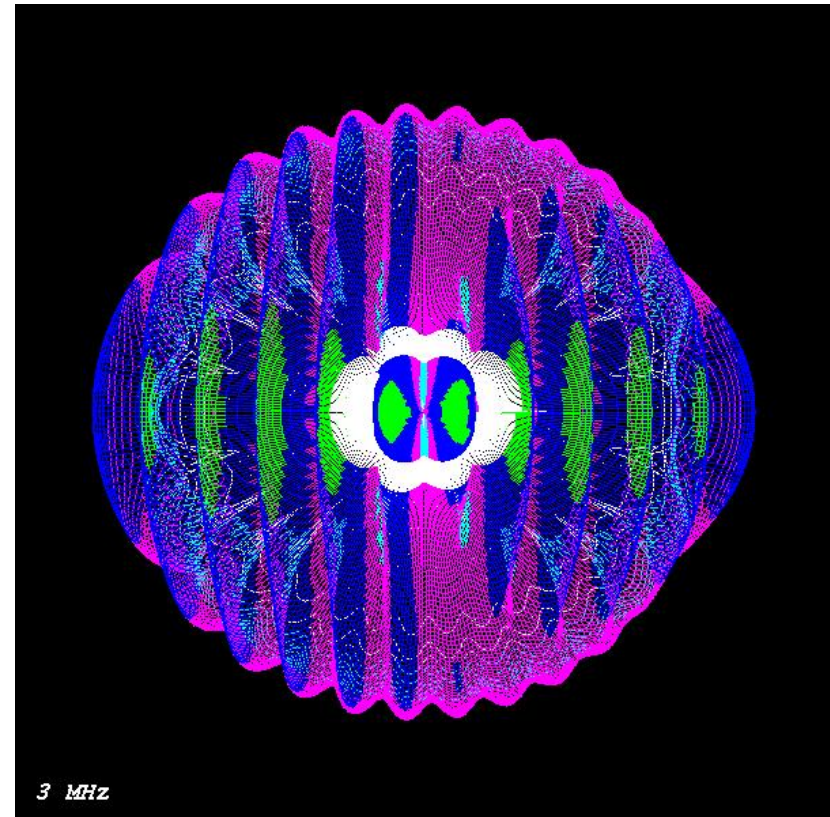
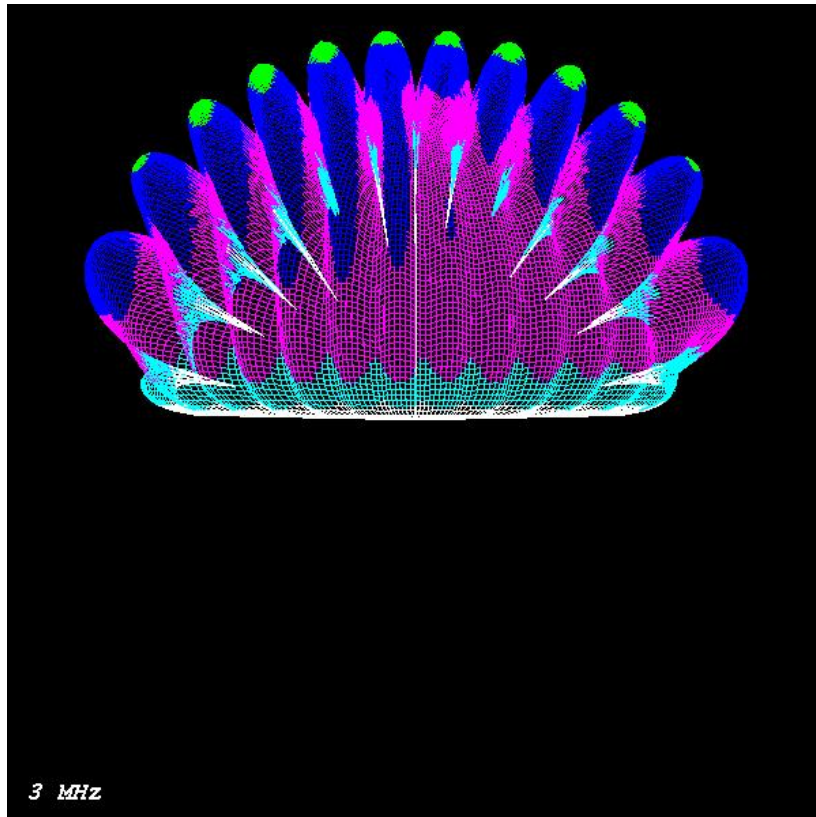


L3M50\_3hpa

L3M50\_3hpb



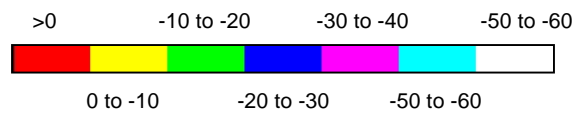
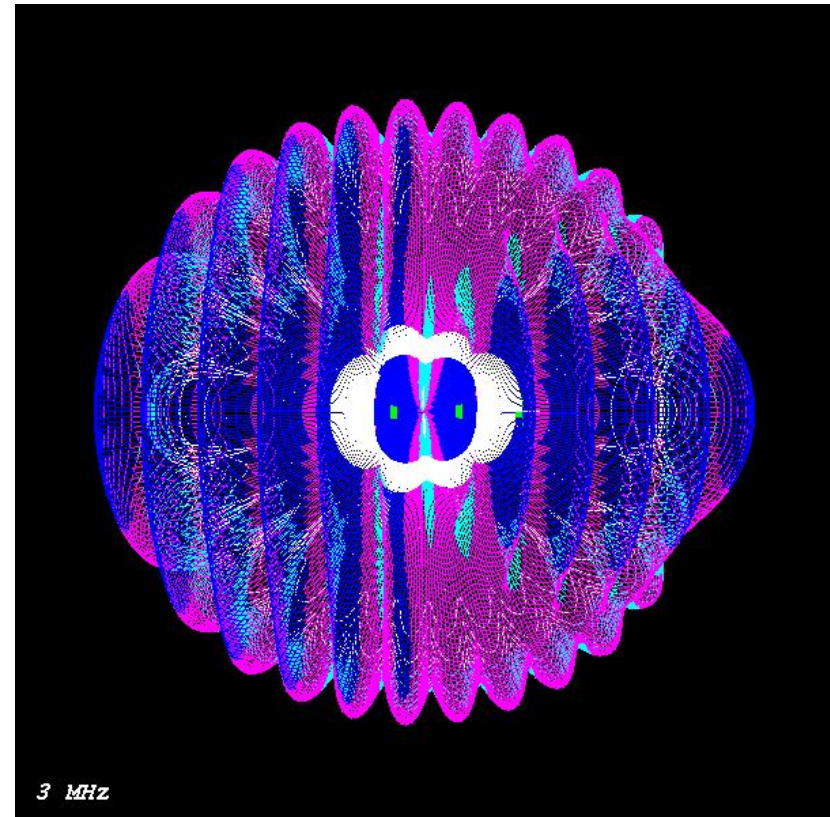
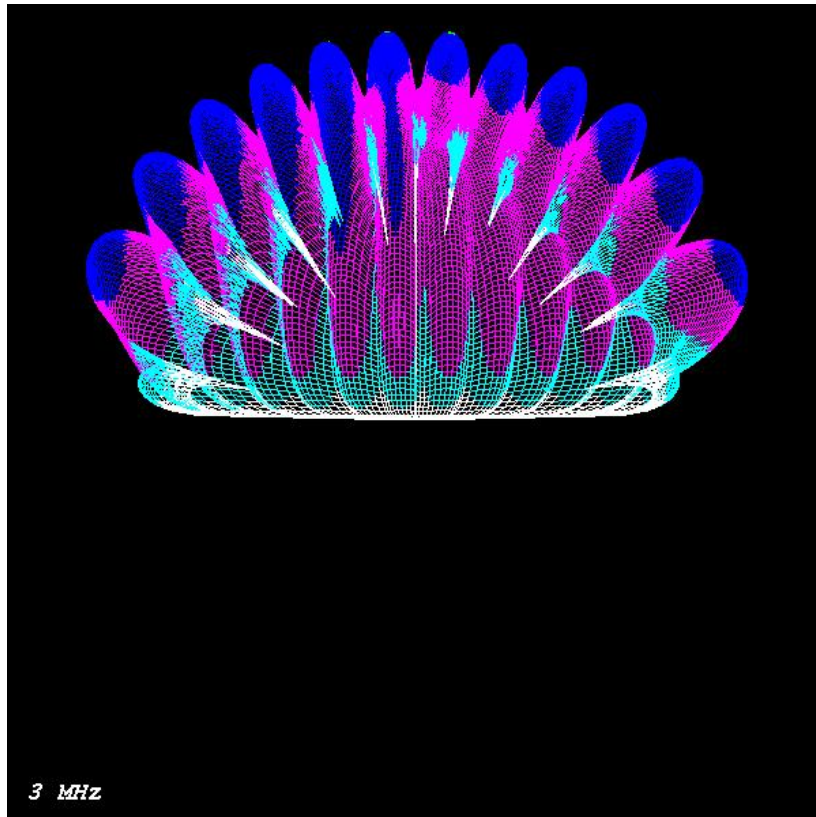
BPL  $Z_{load} = 100 + j0$   $Z_{in} = 201 + j542$   $f = 3.0$  MHz



L3M100\_3hpa

L3M100\_3hpb

BPL  $Z_{load} = 200 + j0$   $Z_{in} = 360 + j456$   $f = 3.0$  MHz

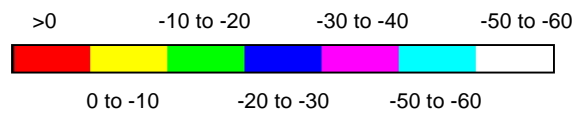
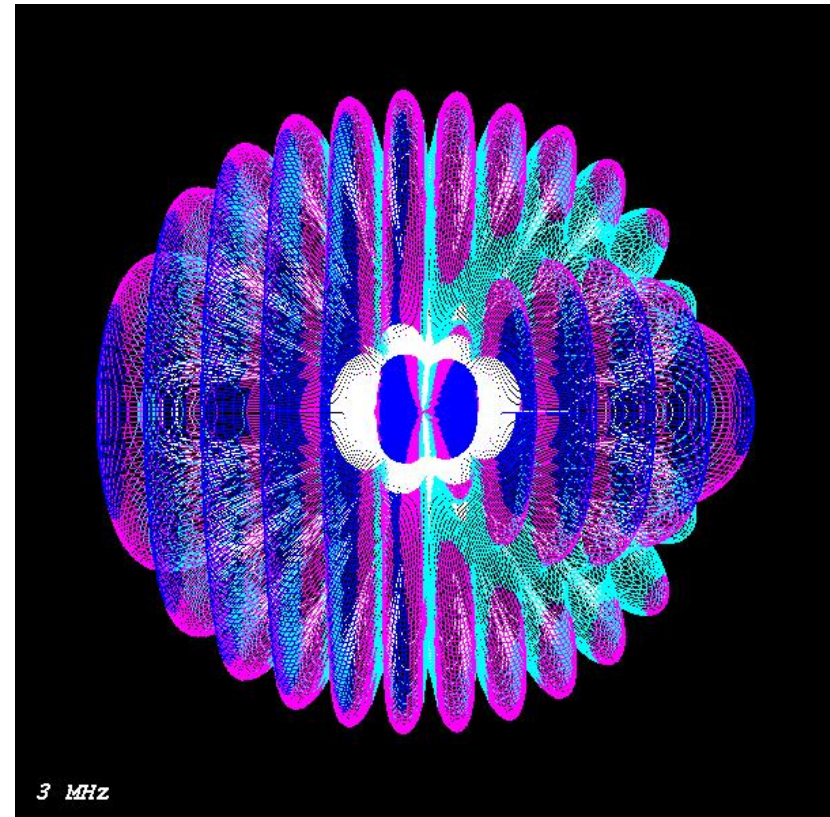
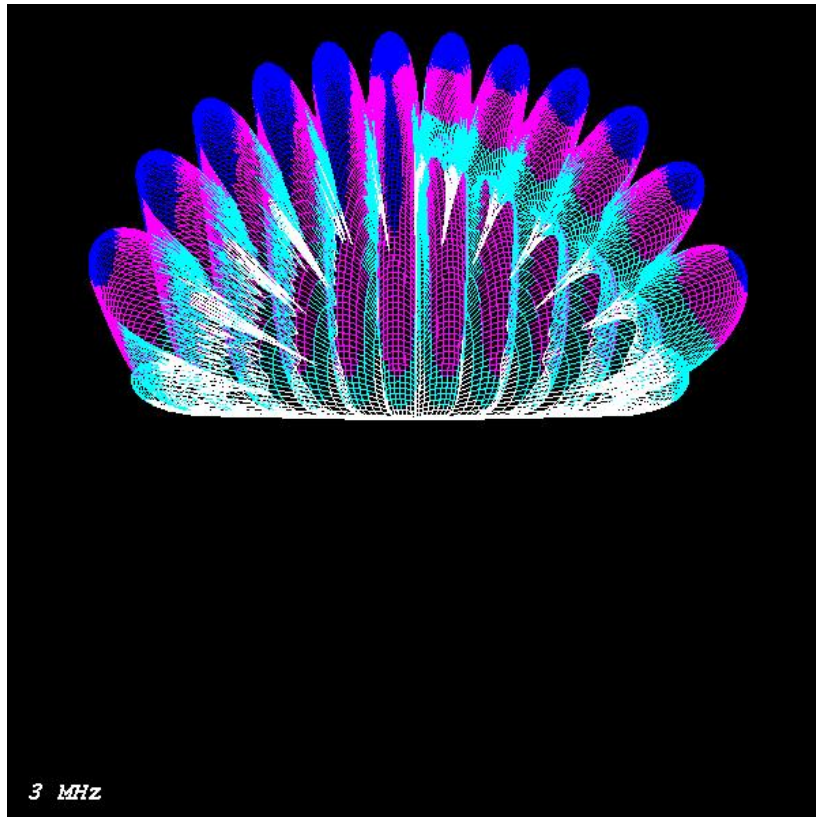


L3M200\_3hpa

L3M200\_3hpb



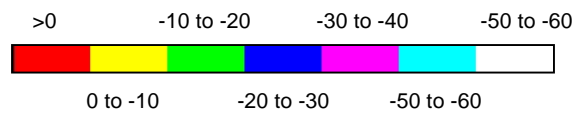
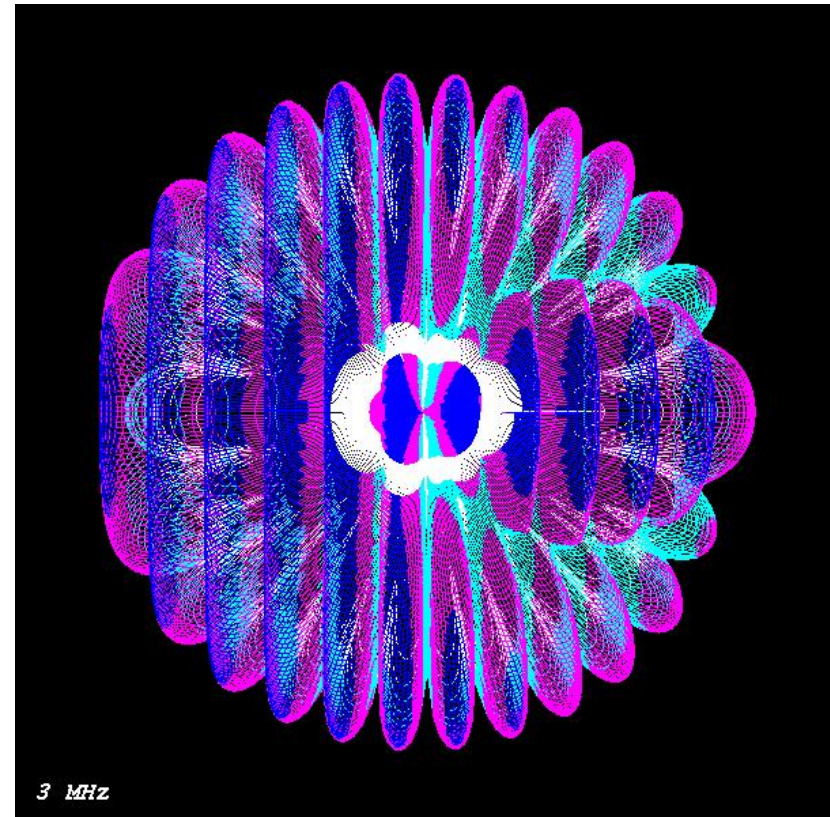
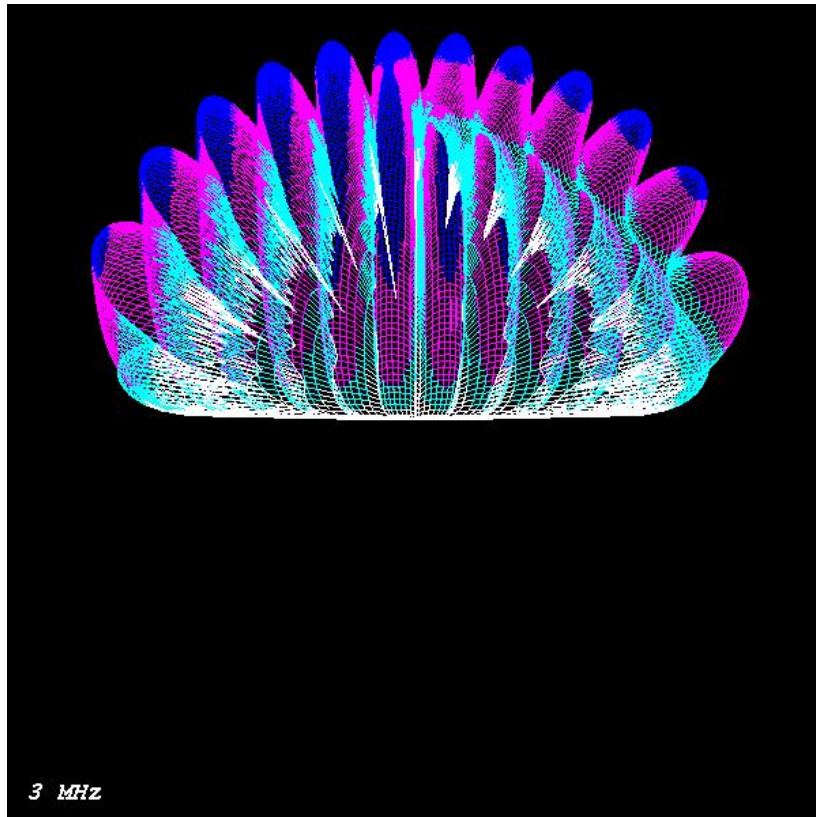
BPL  $Z_{load} = 400 + j0$   $Z_{in} = 546 + j214$   $f = 3.0$  MHz



L3M400\_3hpa

L3M400\_3hpb

BPL  $Z_{load} = 1000 + j0$   $Z_{in} = 548 - j243$   $f = 3.0 \text{ MHz}$

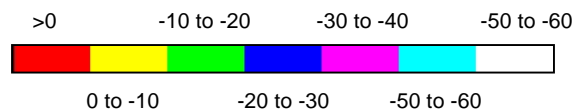
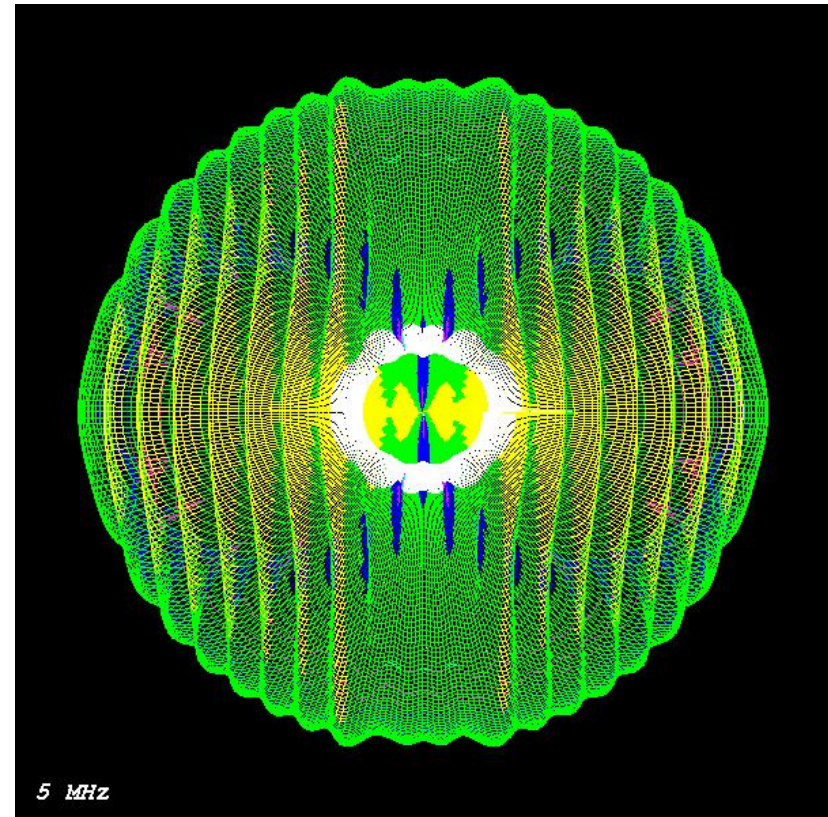
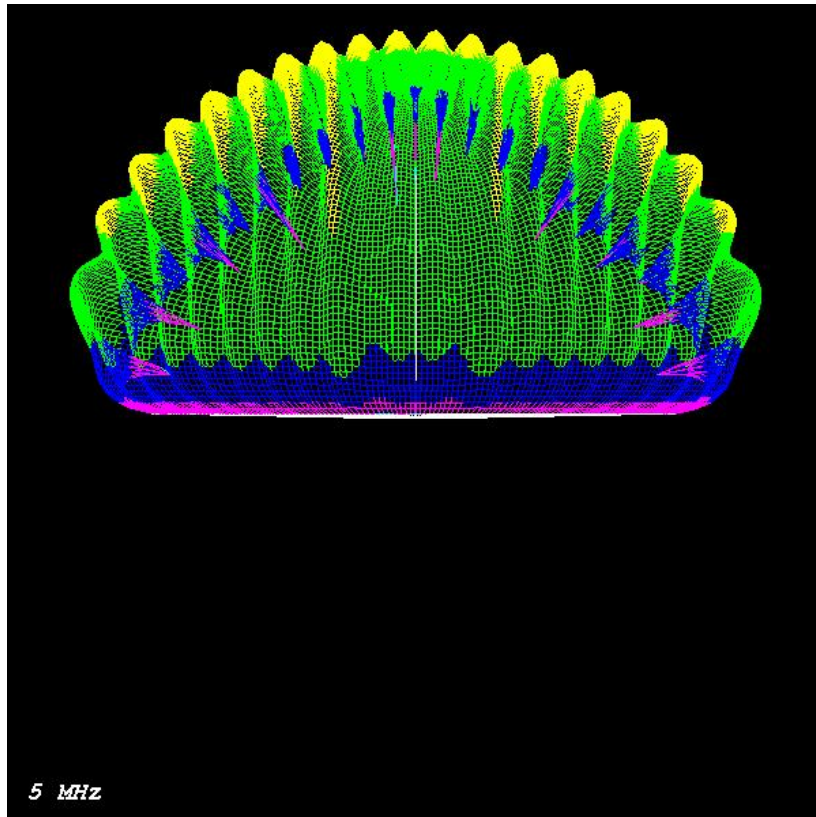


L3M1000\_3hpa

L3M1000\_3hpb



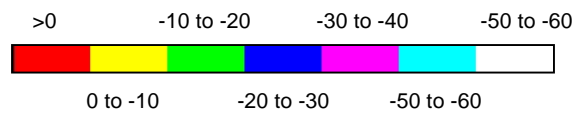
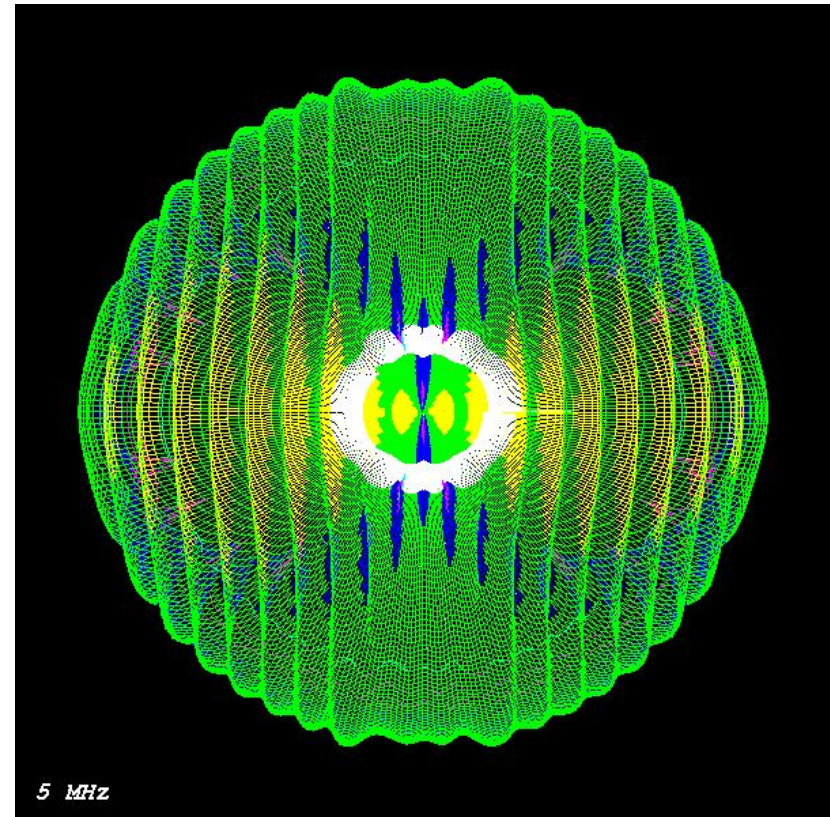
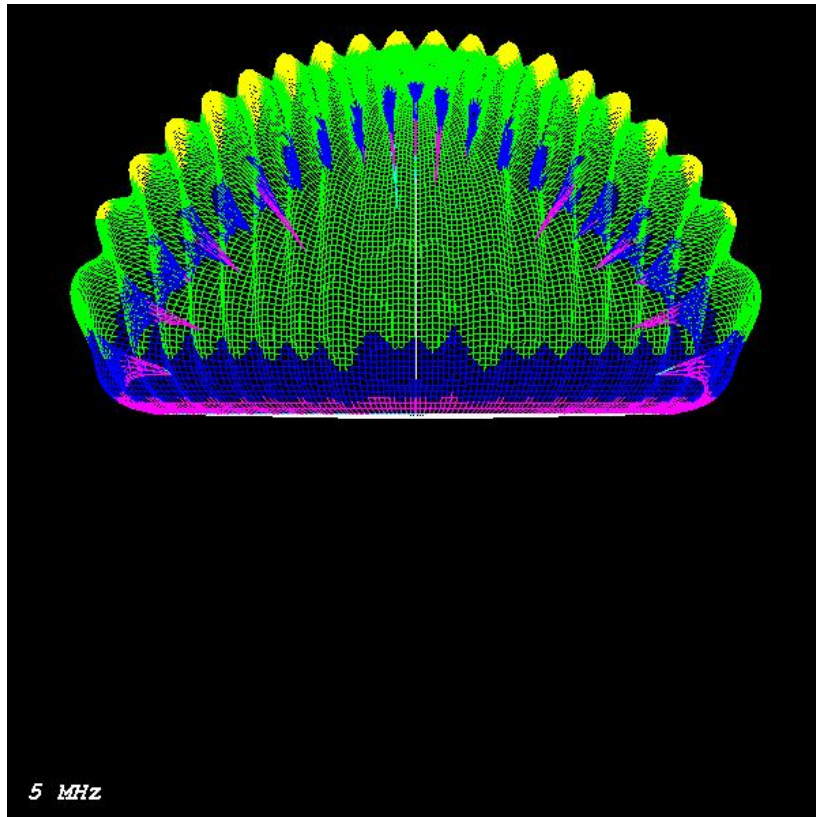
BPL  $Z_{load} = 6.25 + j0$   $Z_{in} = 202 + j2001$   $f = 5.0$  MHz



L5M6\_5hpa

L5M6\_5hpb

BPL  $Z_{load} = 12.5 + j0$   $Z_{in} = 277 + j1985$   $f = 5.0$  MHz

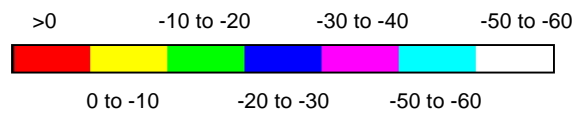
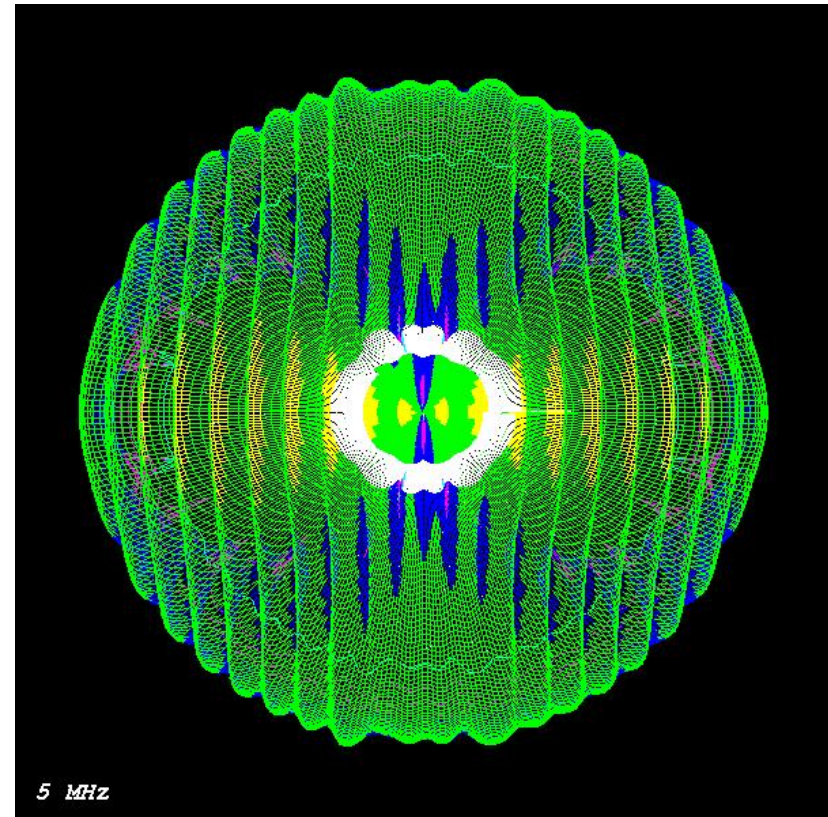
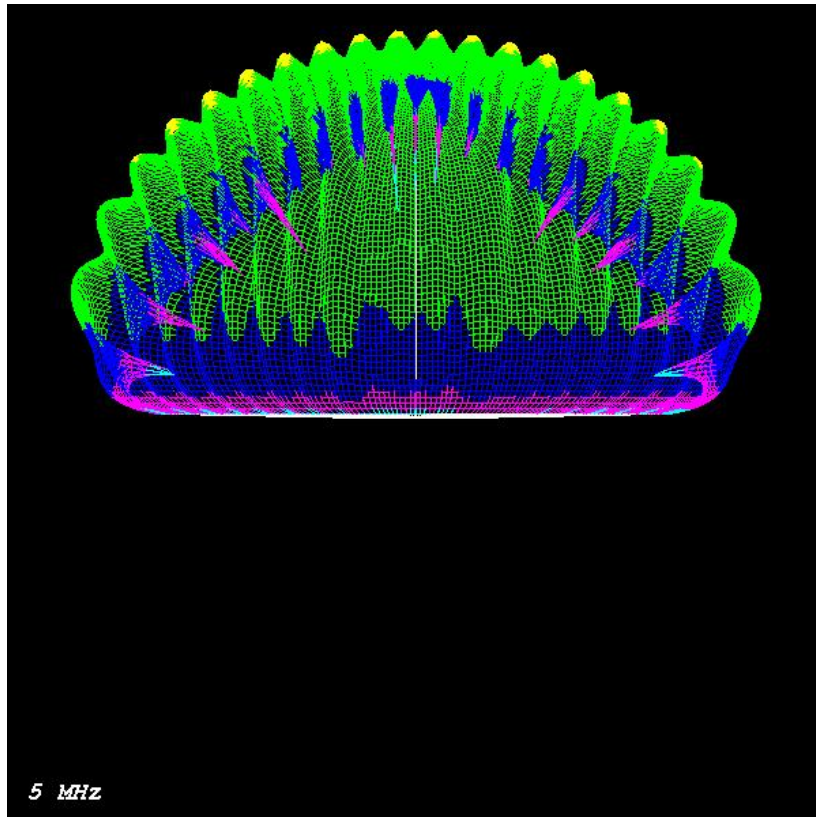


L5M12\_5hpa

L5M12\_5hpb



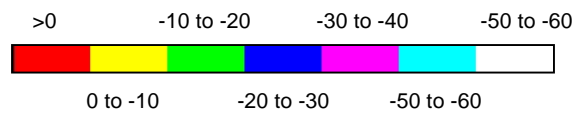
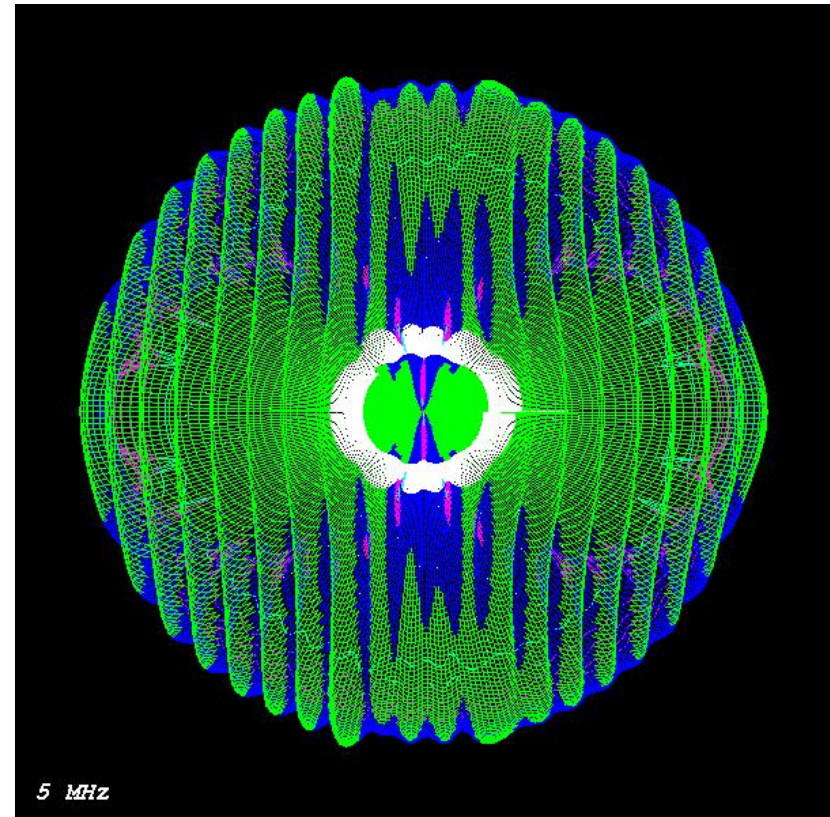
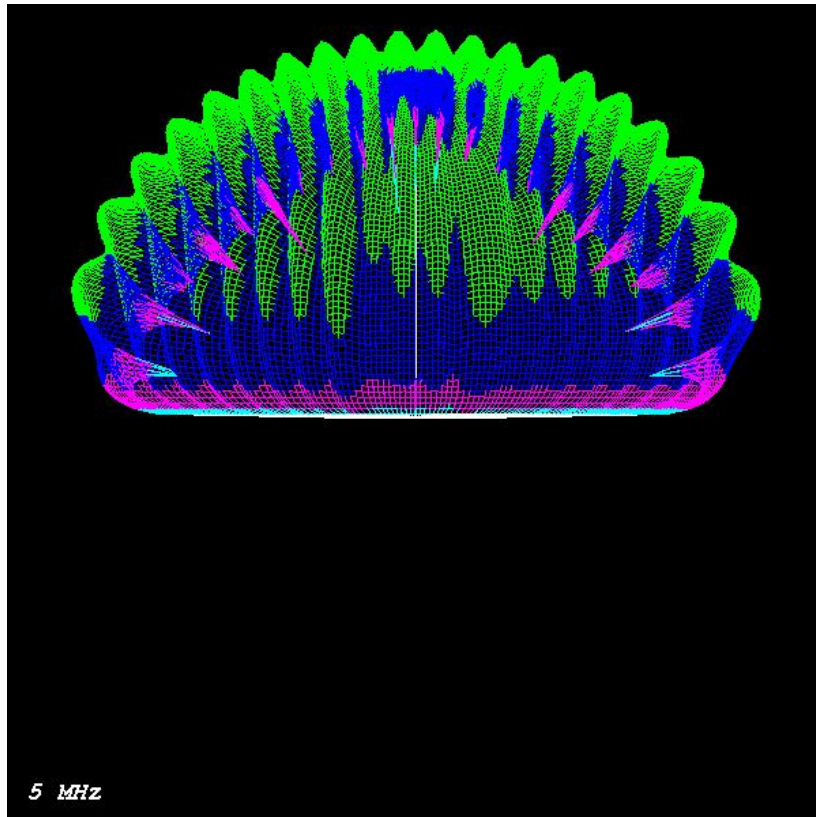
BPL  $Z_{load} = 25 + j0$   $Z_{in} = 421 + j1936$   $f = 5.0$  MHz



L5M25\_5hpa

L5M25\_5hpb

BPL  $Z_{load} = 50 + j0$   $Z_{in} = 672 + j1792$   $f = 5.0$  MHz

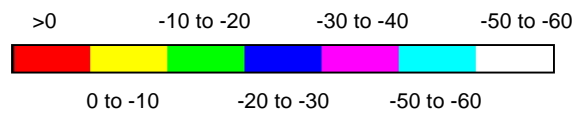
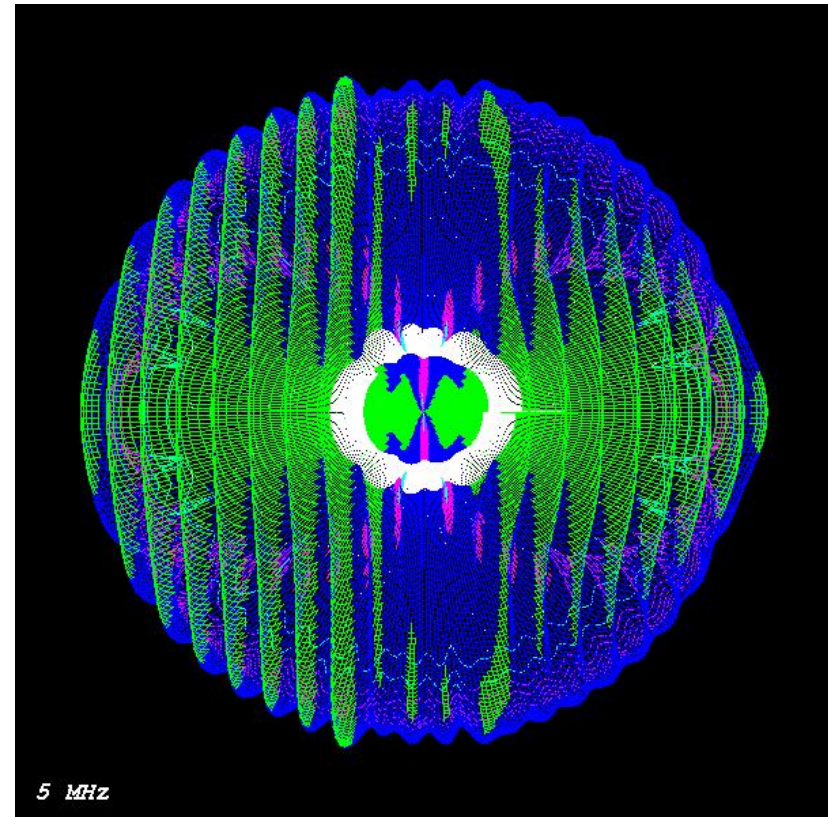
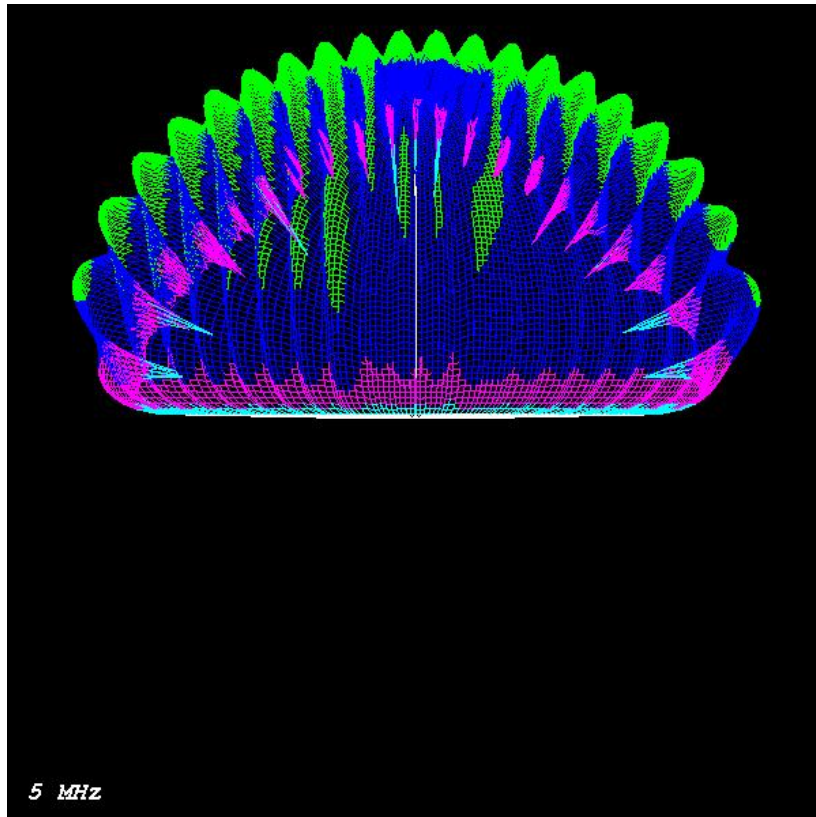


L5M50\_5hpa

L5M50\_5hpb



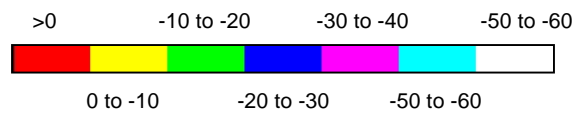
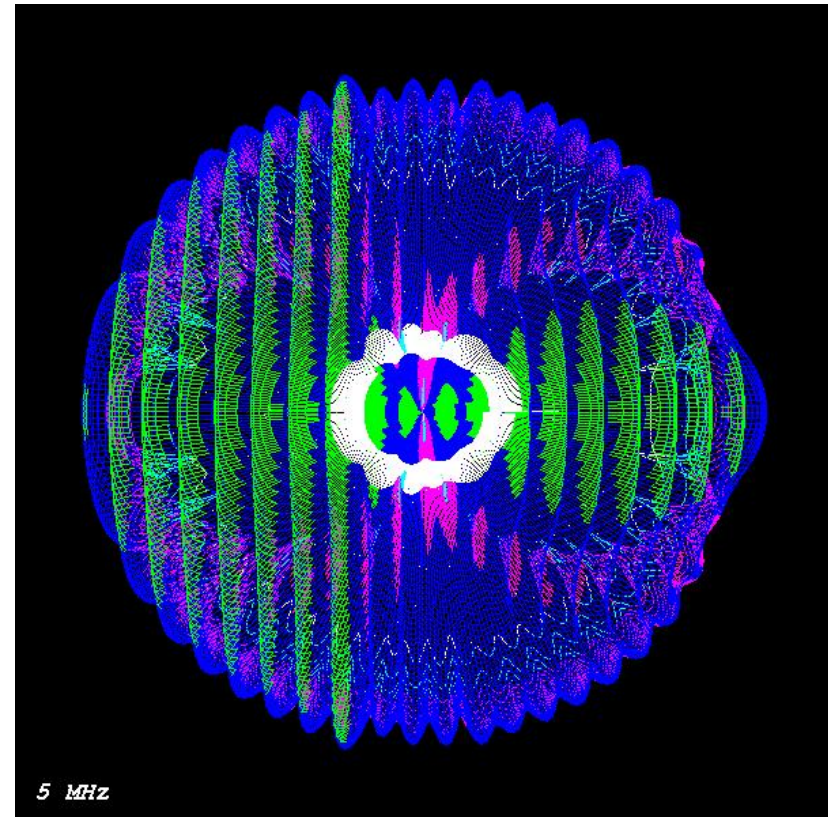
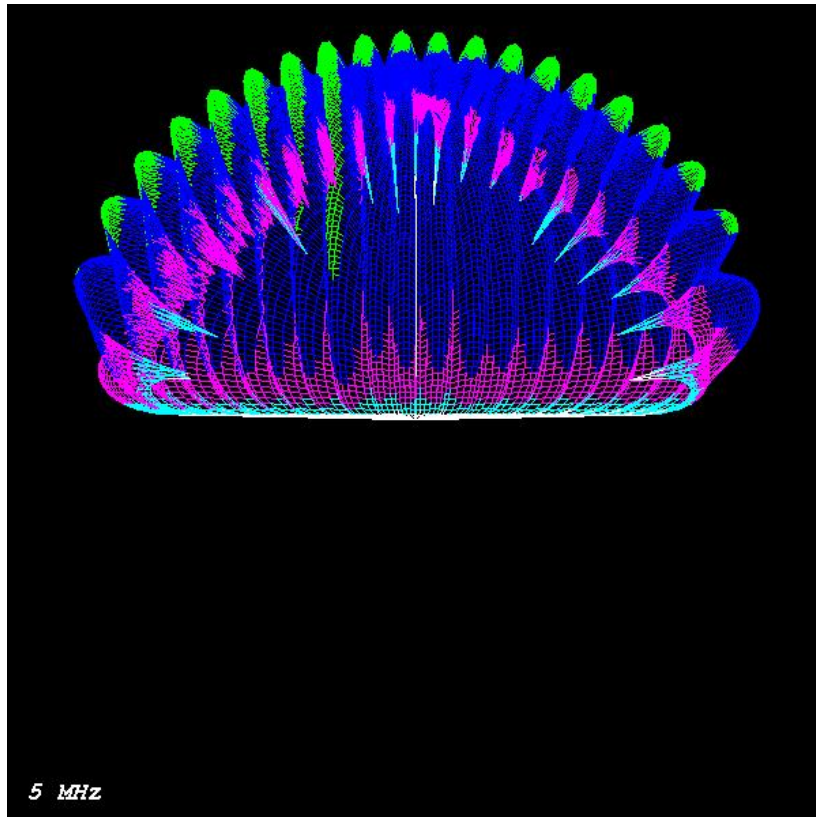
BPL  $Z_{load} = 100 + j0$   $Z_{in} = 988 + j1404$   $f = 5.0$  MHz



L5M100\_5hpa

L5M100\_5hpb

BPL  $Z_{load} = 200 + j0$   $Z_{in} = 1083 + j733$   $f = 5.0$  MHz

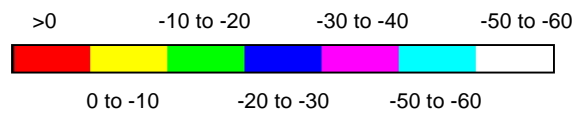
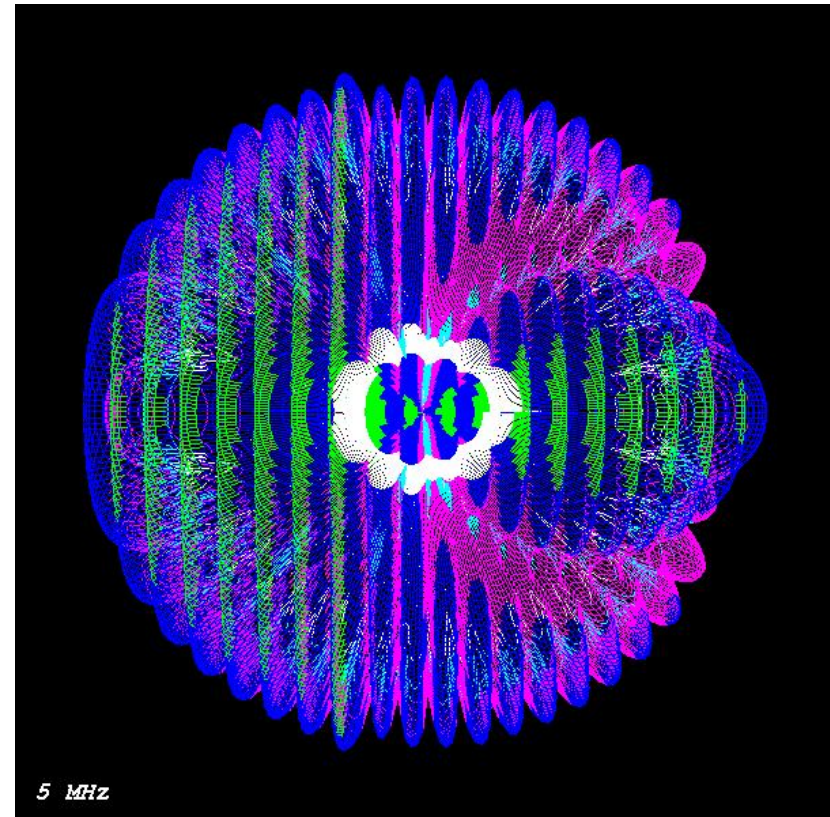
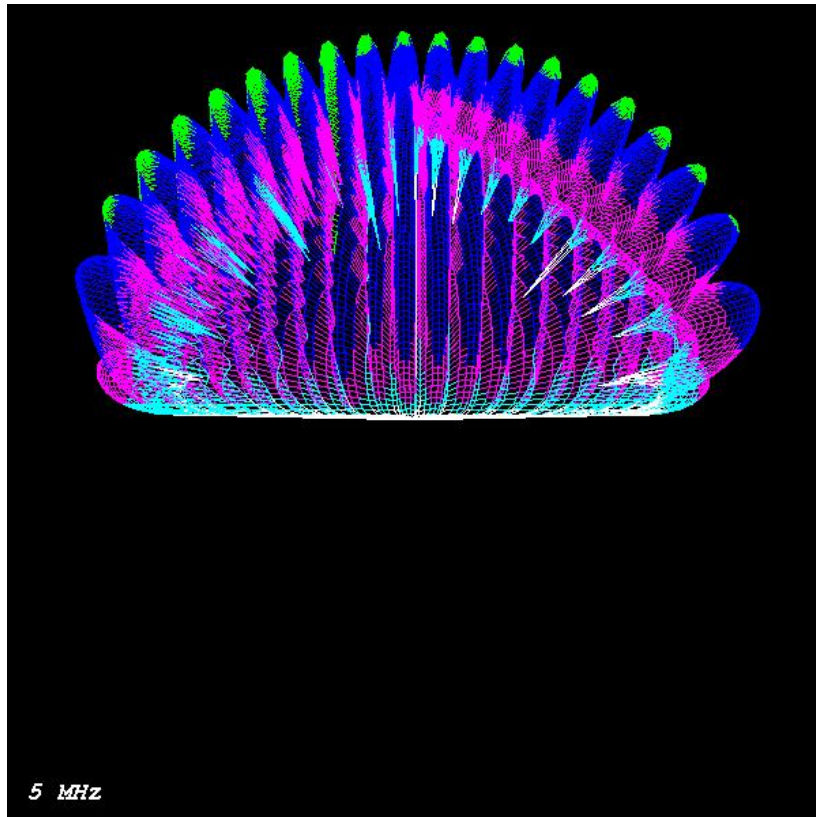


L5M200\_5hpa

L5M200\_5hpb



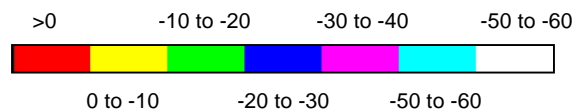
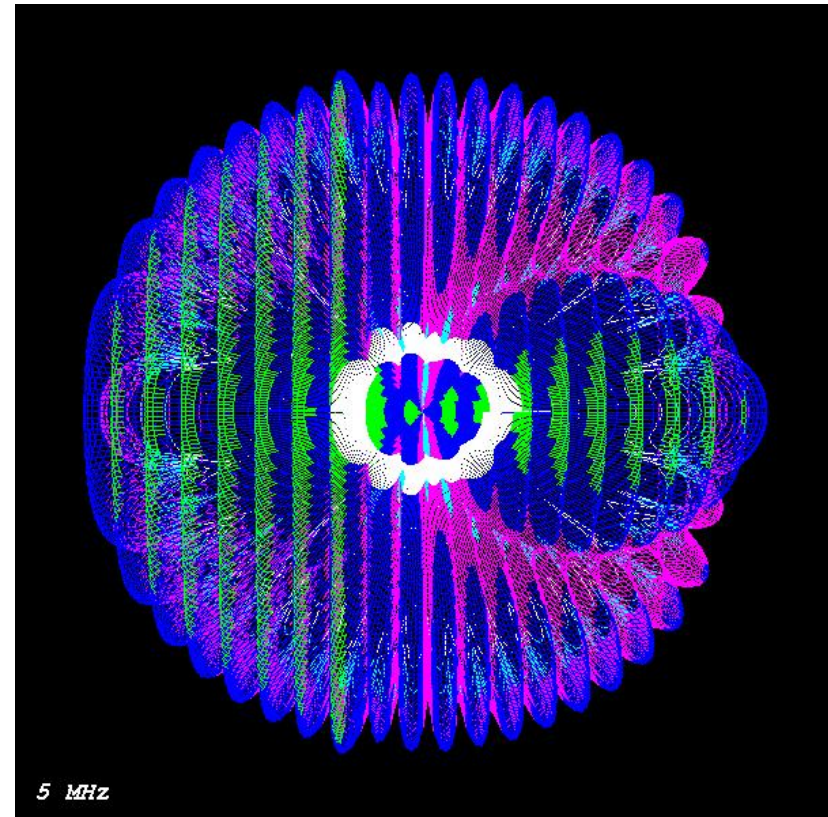
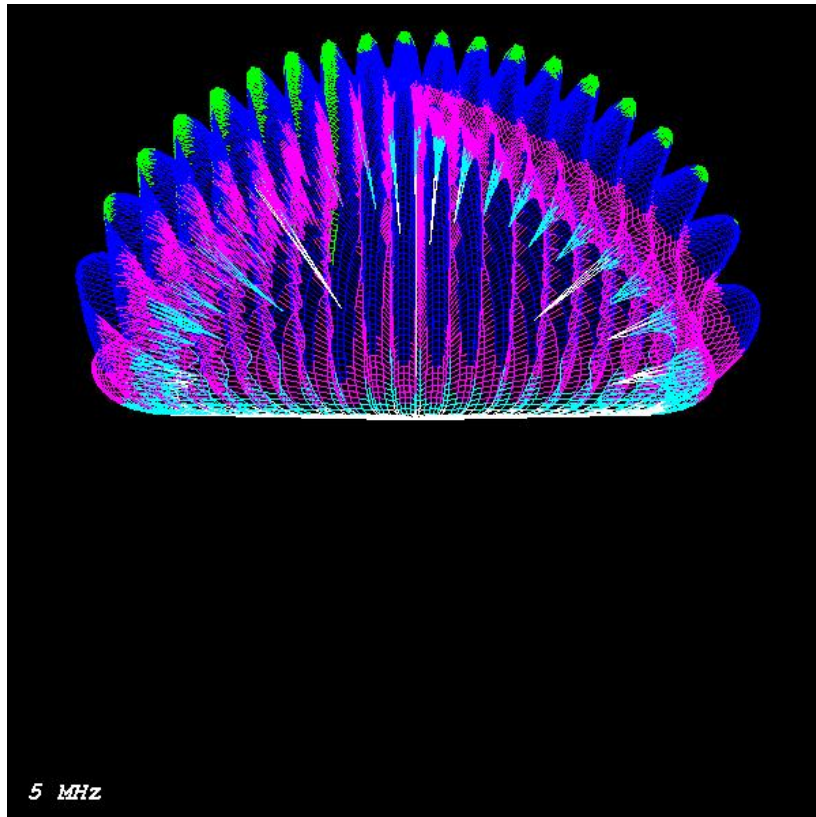
BPL  $Z_{load} = 400 + j0$   $Z_{in} = 801 + j170$   $f = 5.0$  MHz



L5M400\_5hpa

L5M400\_5hpb

BPL  $Z_{load} = 1000 + j0$   $Z_{in} = 380 - j108$   $f = 5.0$  MHz

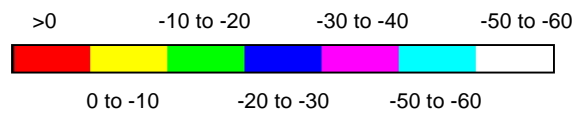
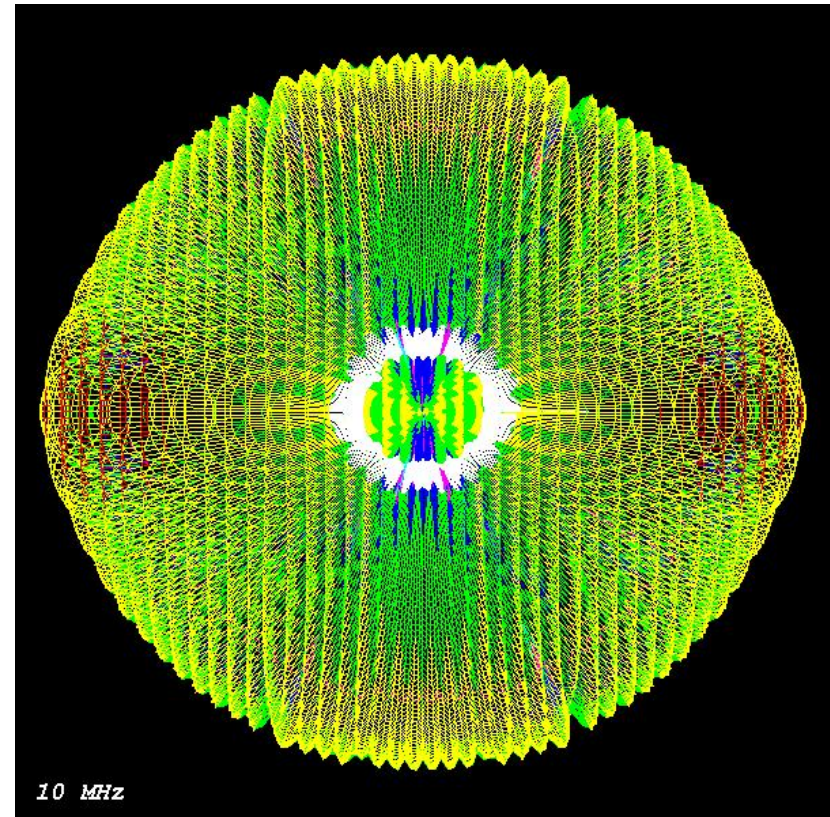
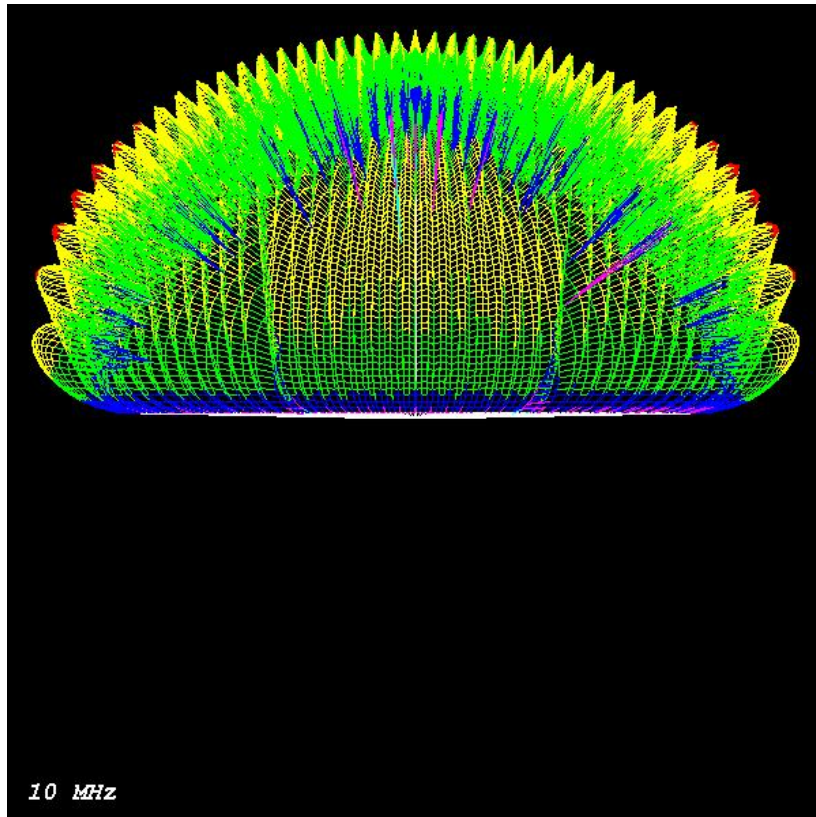


L5M1000\_5hpa

L5M1000\_5hpb



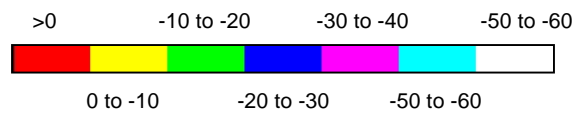
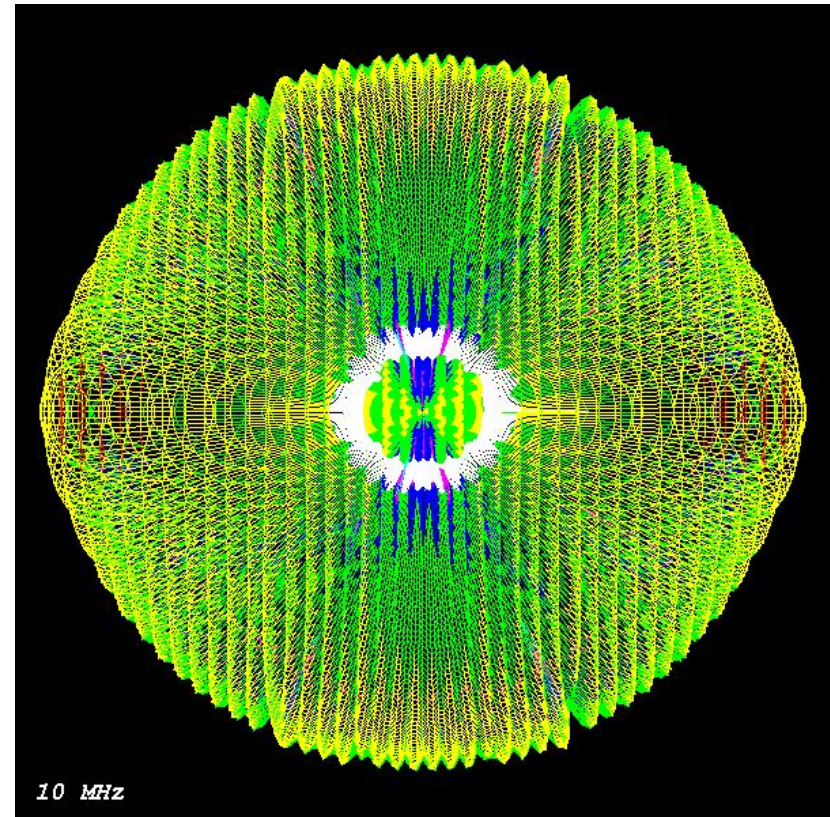
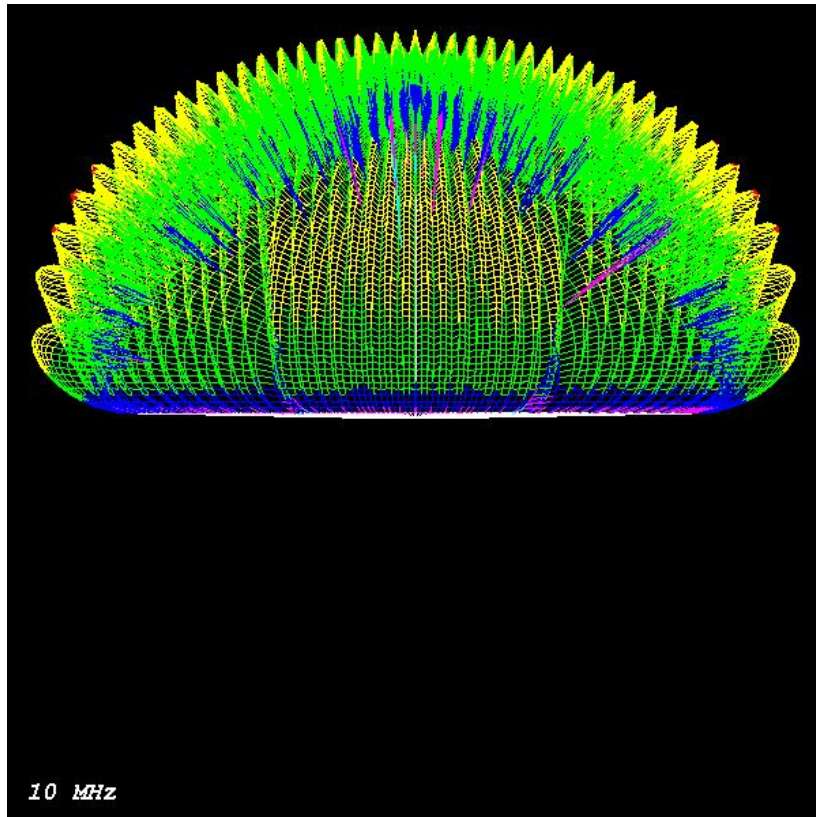
BPL  $Z_{load} = 6.25 + j0$   $Z_{in} = 40 - j430$   $f = 10.0$  MHz



L10M6\_10hpa

L10M6\_10hpb

BPL  $Z_{load} = 12.5 + j0$   $Z_{in} = 49 - j430$   $f = 10.0$  MHz

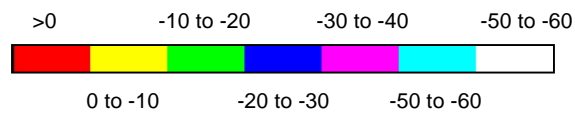
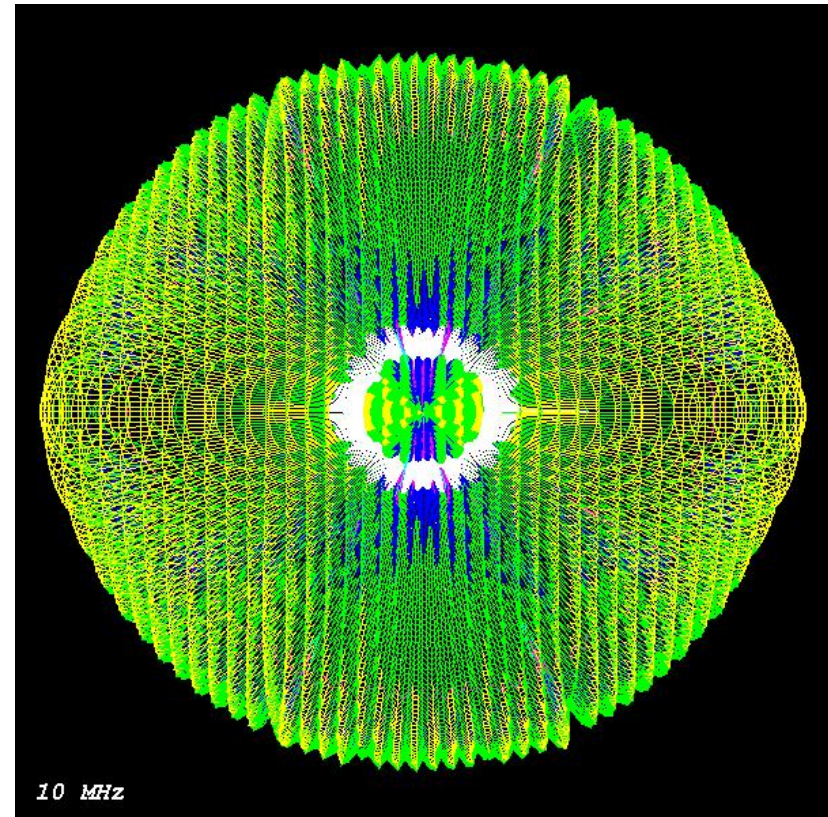
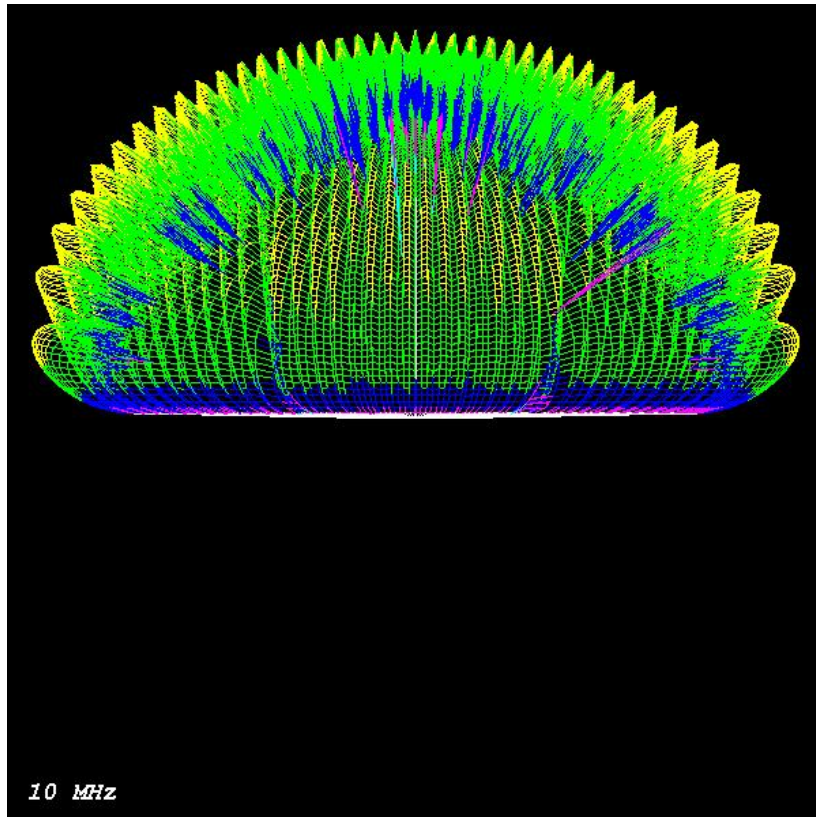


L10M12\_10hpa

L10M12\_10hpb



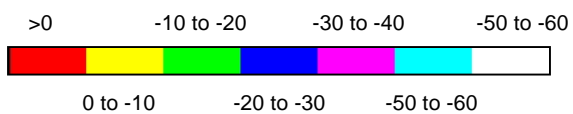
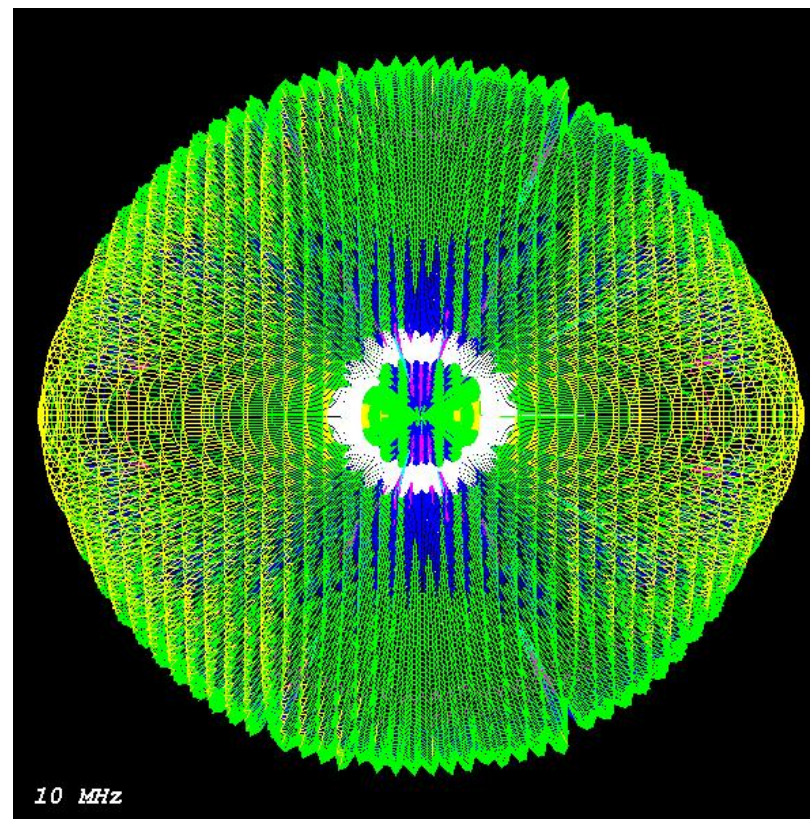
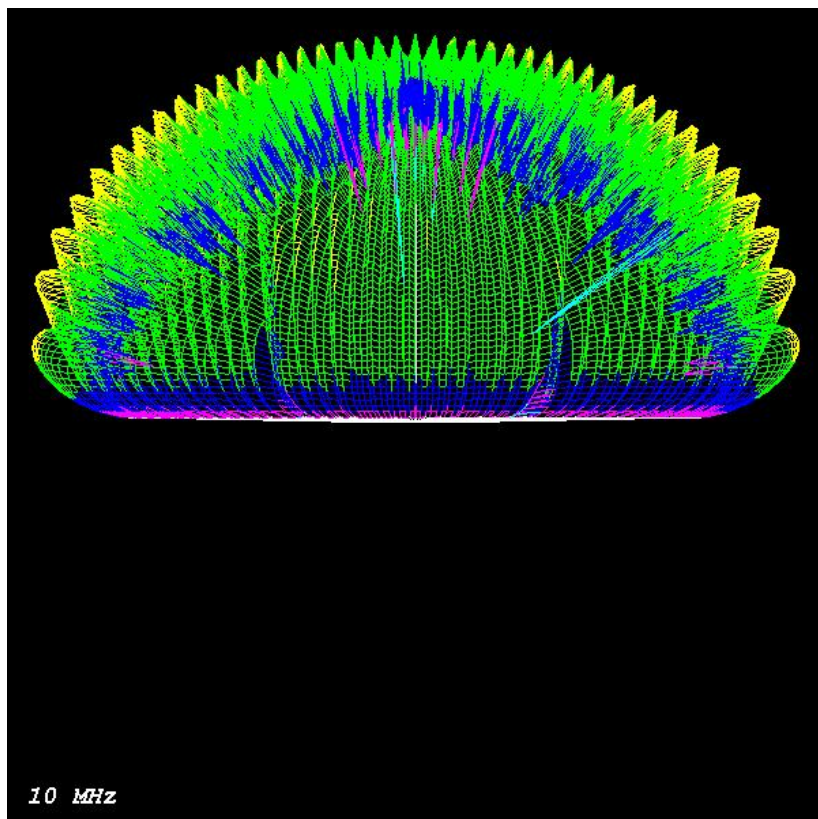
BPL  $Z_{load} = 25 + j0$   $Z_{in} = 67 - j428$   $f = 10.0$  MHz



L10M25\_10hpa

L10M25\_10hpb

BPL  $Z_{load} = 50 + j0$   $Z_{in} = 102 - j424$   $f = 10.0$  MHz

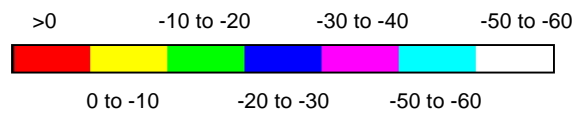
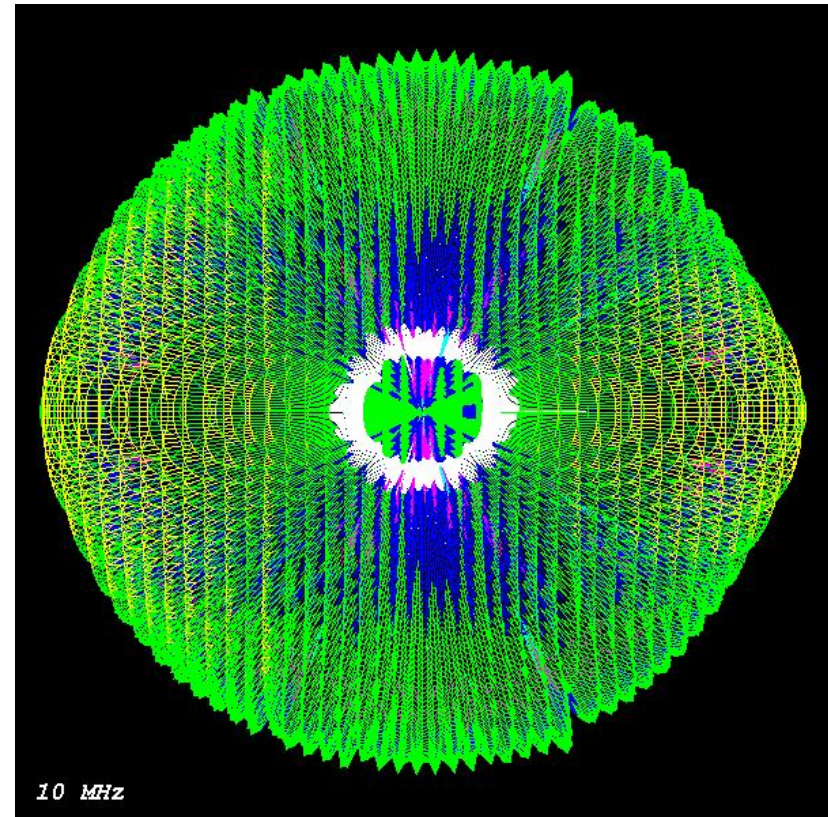
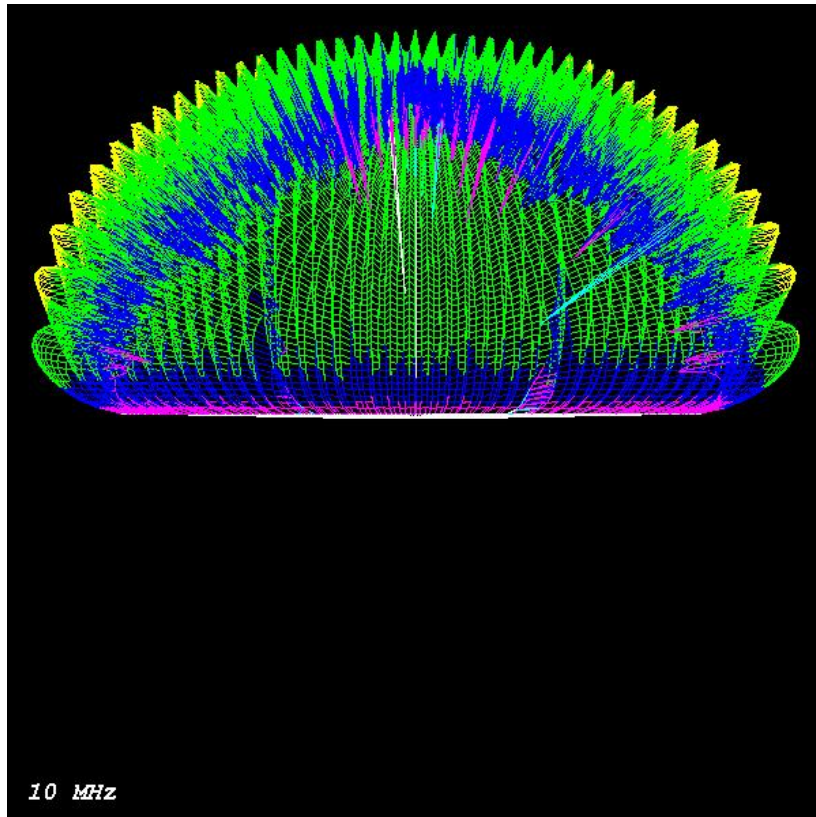


L10M50\_10hpa

L10M50\_10hpb



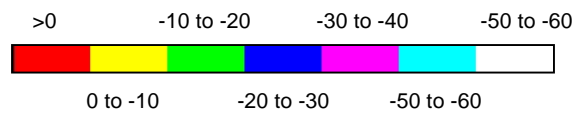
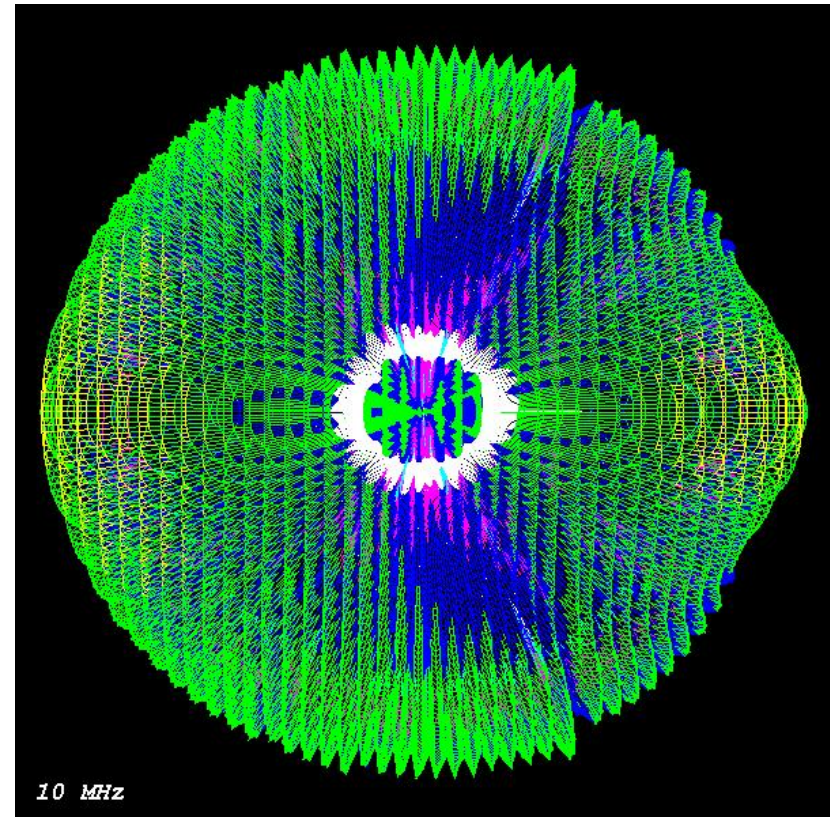
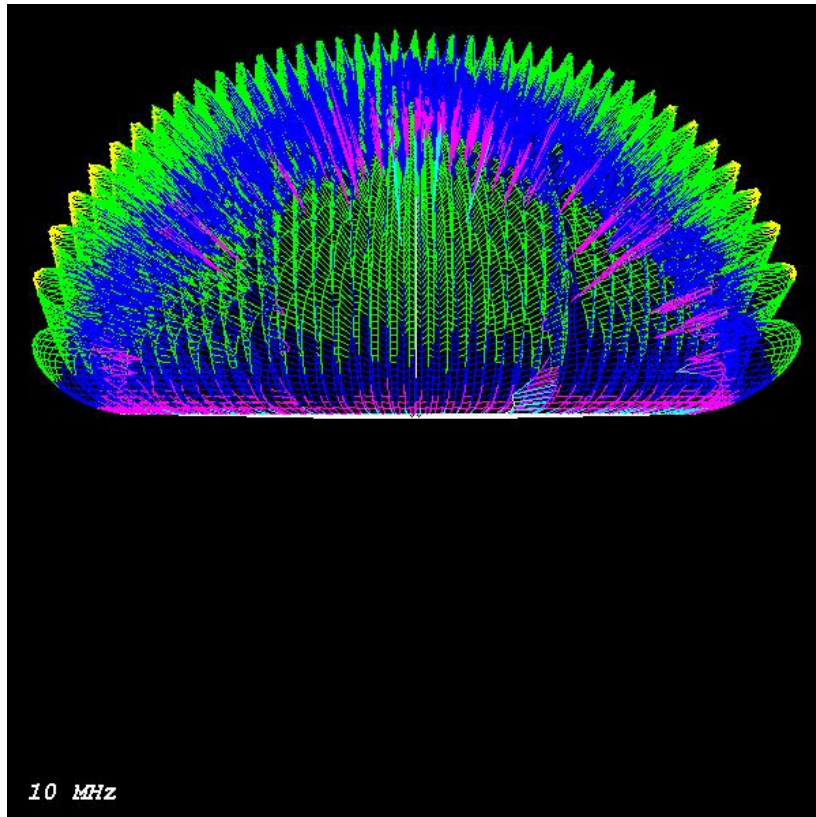
BPL  $Z_{load} = 100 + j0$   $Z_{in} = 172 - j410$   $f = 10.0$  MHz



L10M100\_10hpa

L10M100\_10hpb

BPL  $Z_{load} = 200 + j0$   $Z_{in} = 301 - j363$   $f = 10.0$  MHz

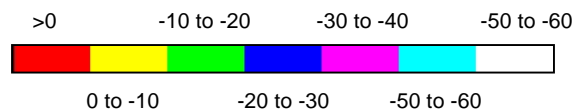
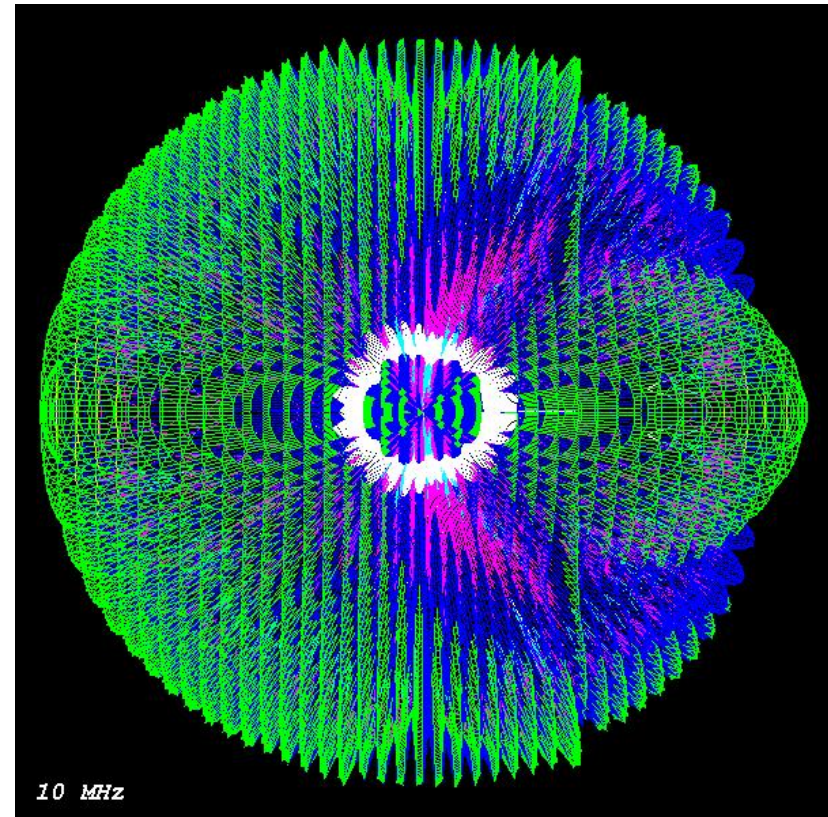
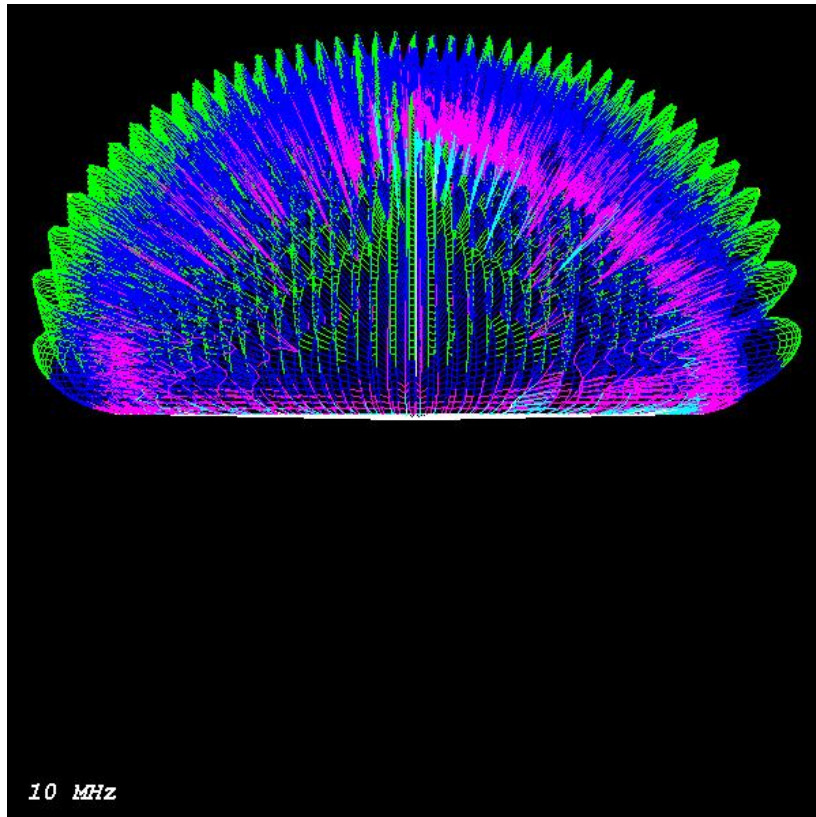


L10M200\_10hpa

L10M200\_10hpb



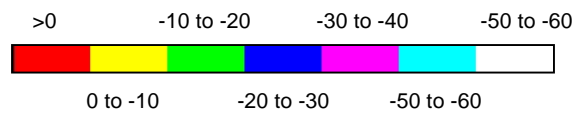
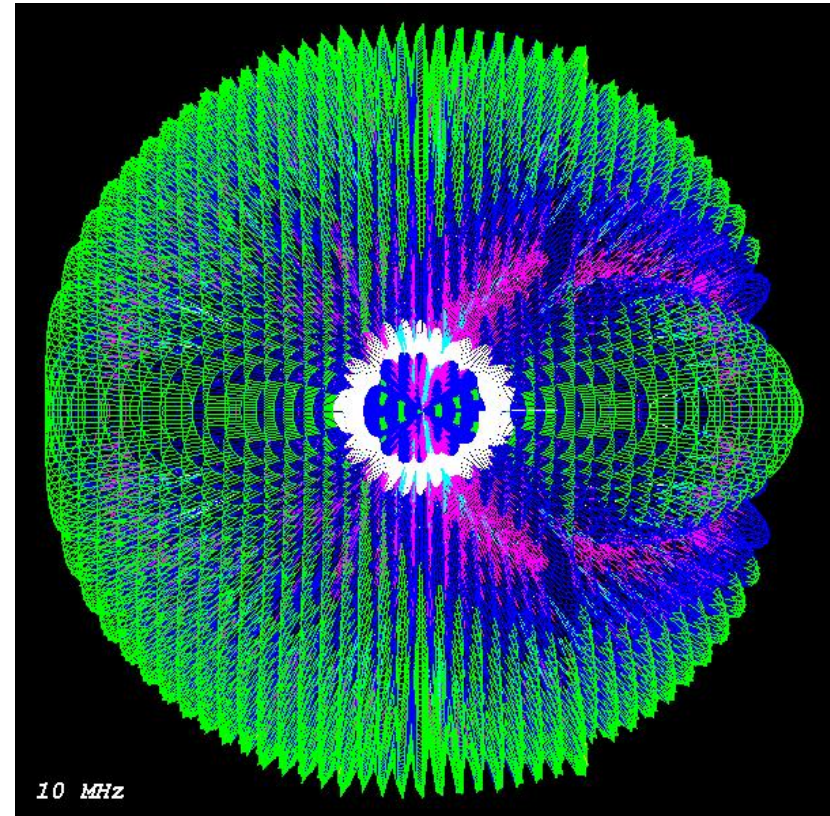
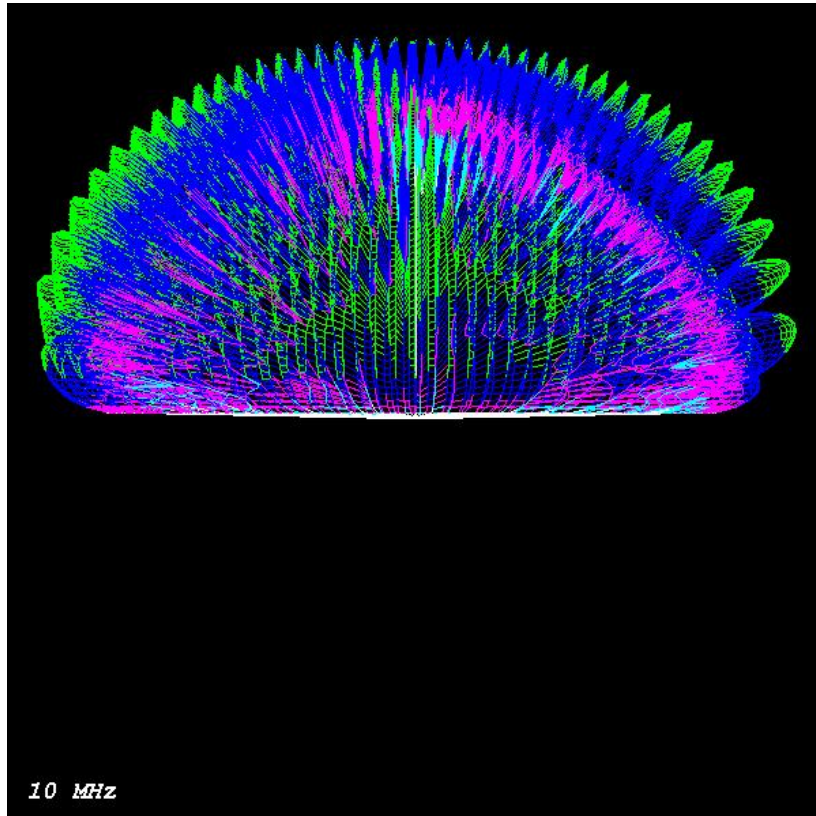
BPL  $Z_{load} = 400 + j0$   $Z_{in} = 503 - j216$   $f = 10.0$  MHz



L10M400\_10hpa

L10M400\_10hpb

BPL  $Z_{load} = 1000 + j0$   $Z_{in} = 697 + j268$   $f = 10.0$  MHz

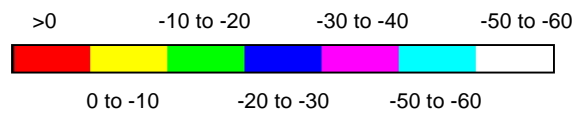
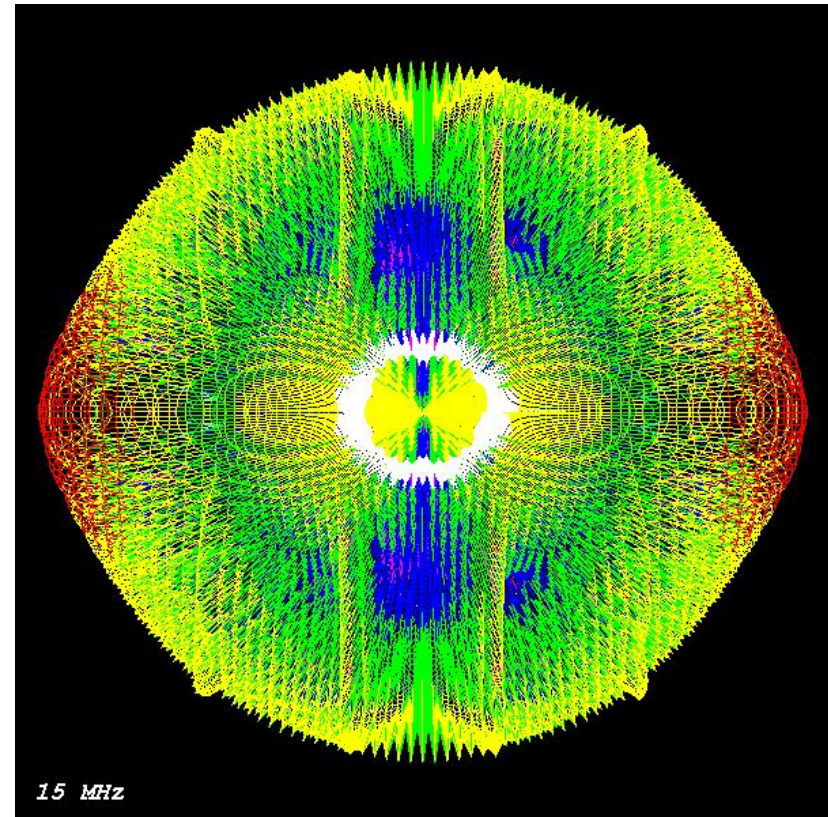
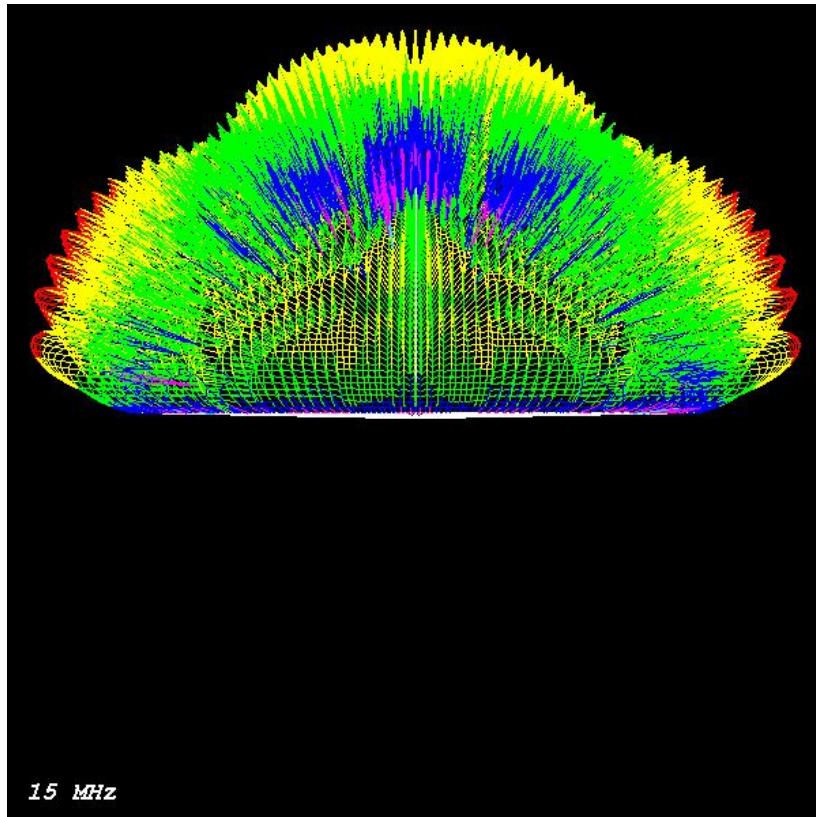


L10M1000\_10hpa

L10M1000\_10hpb



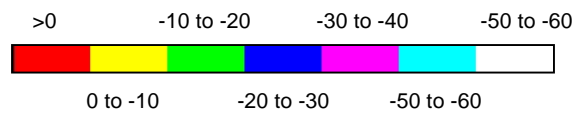
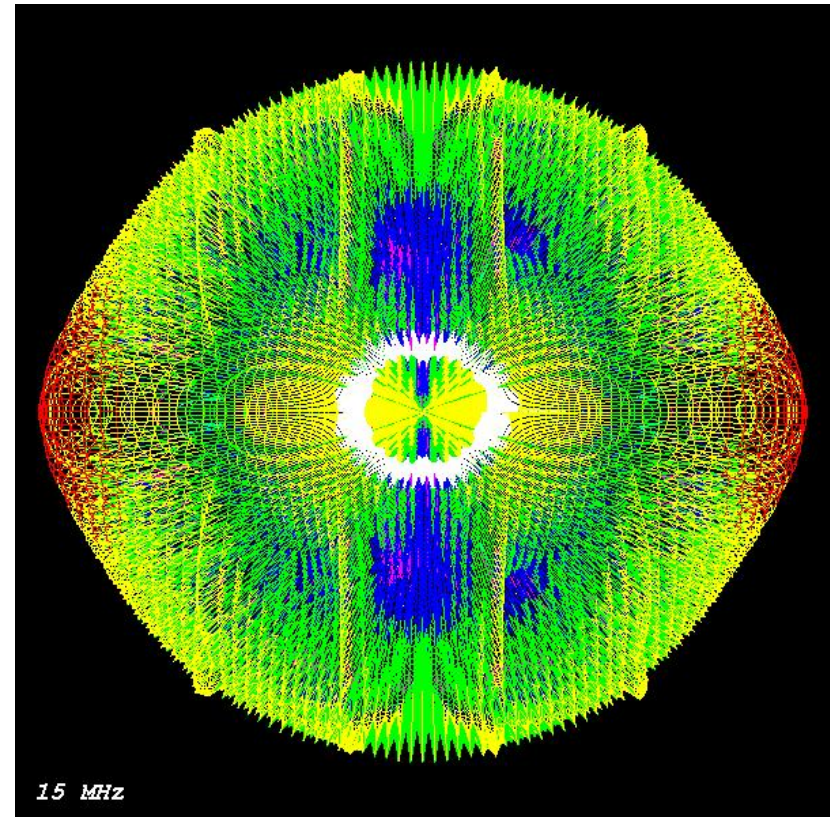
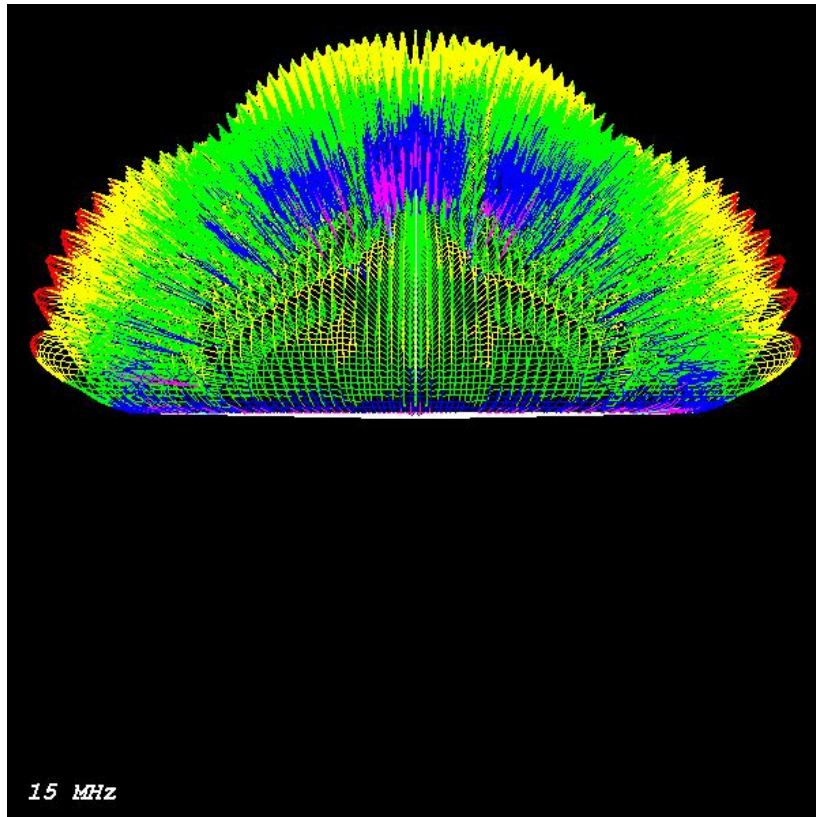
BPL  $Z_{load} = 6.25 + j0$   $Z_{in} = 43 + j428$   $f = 15.0$  MHz



L15M6\_15hpa

L15M6\_15hpb

BPL  $Z_{load} = 12.5 + j0$   $Z_{in} = 54 + j427$   $f = 15.0$  MHz

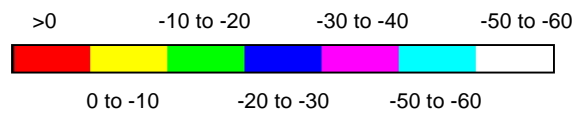
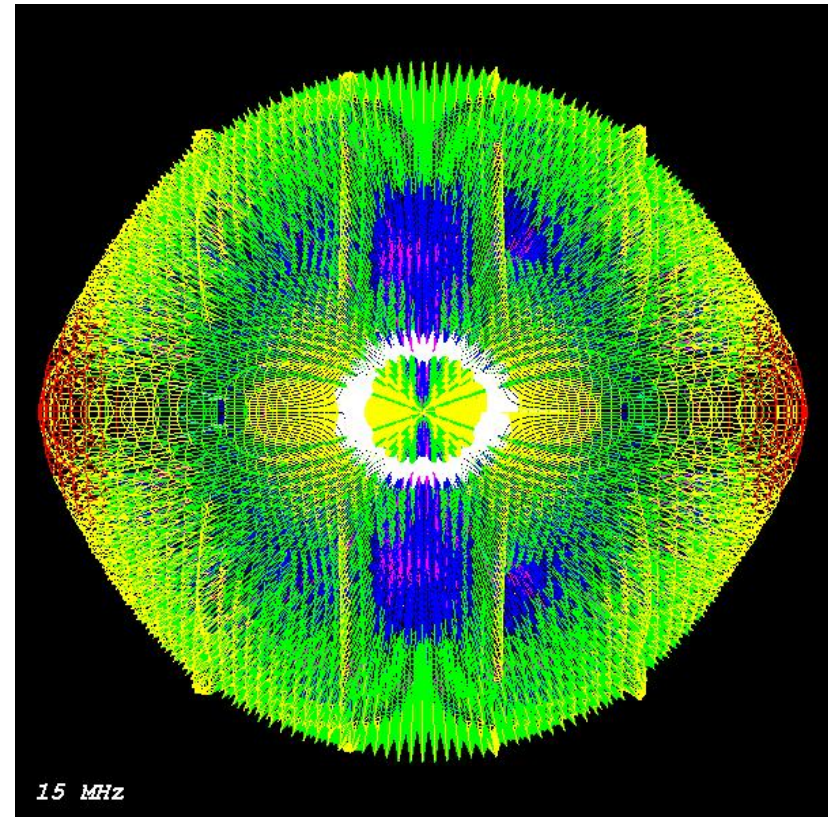
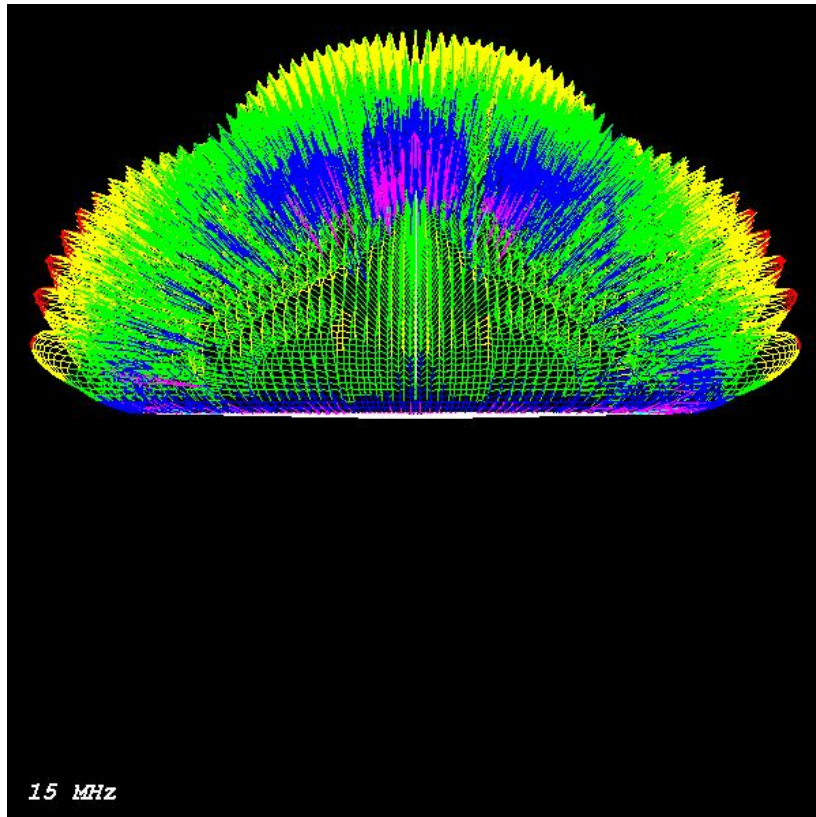


L15M12\_15hpa

L15M12\_15hpb



BPL  $Z_{load} = 25 + j0$   $Z_{in} = 74 + j425$   $f = 15.0$  MHz

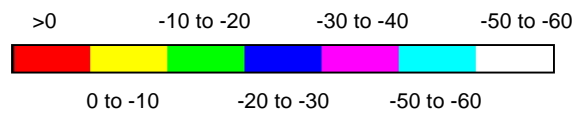
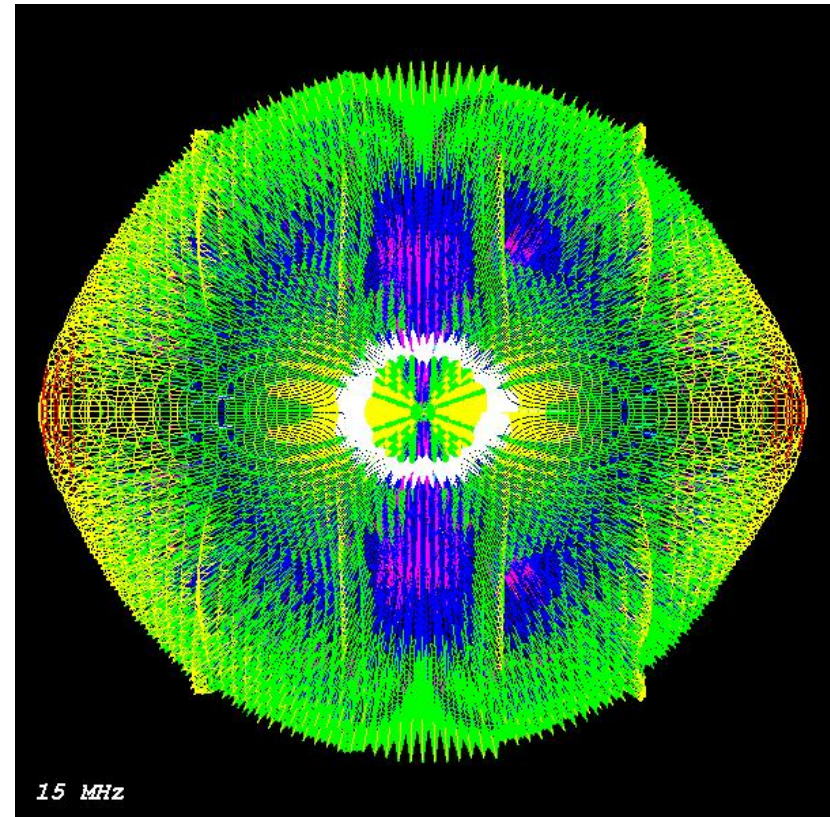
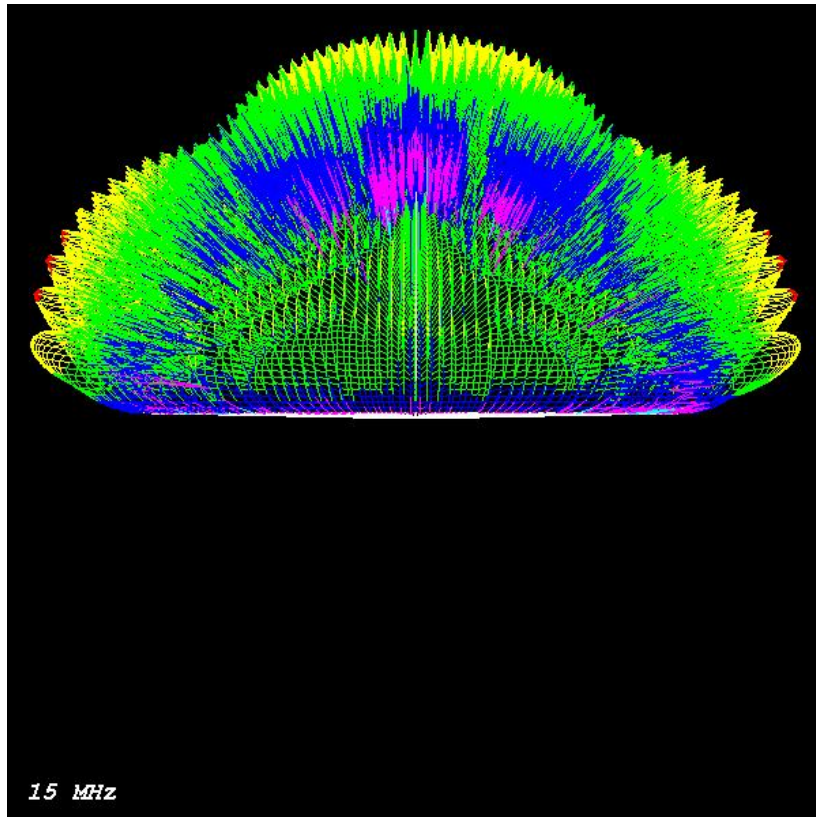


L15M25\_15hpa

L15M25\_15hpb



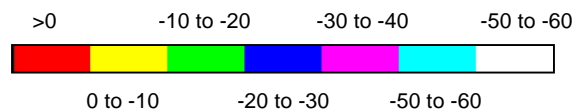
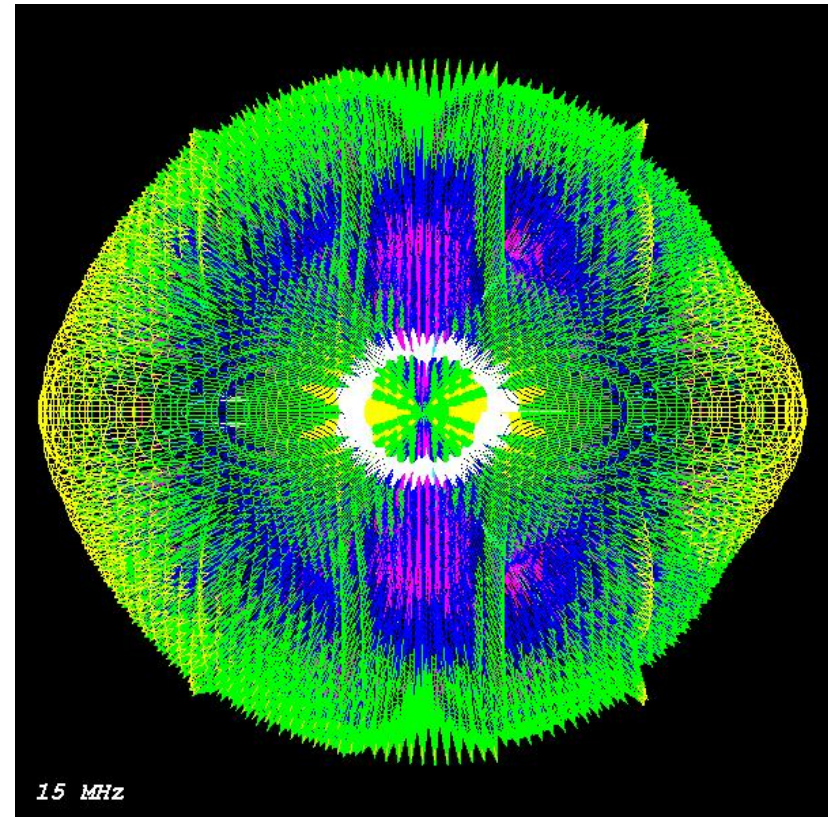
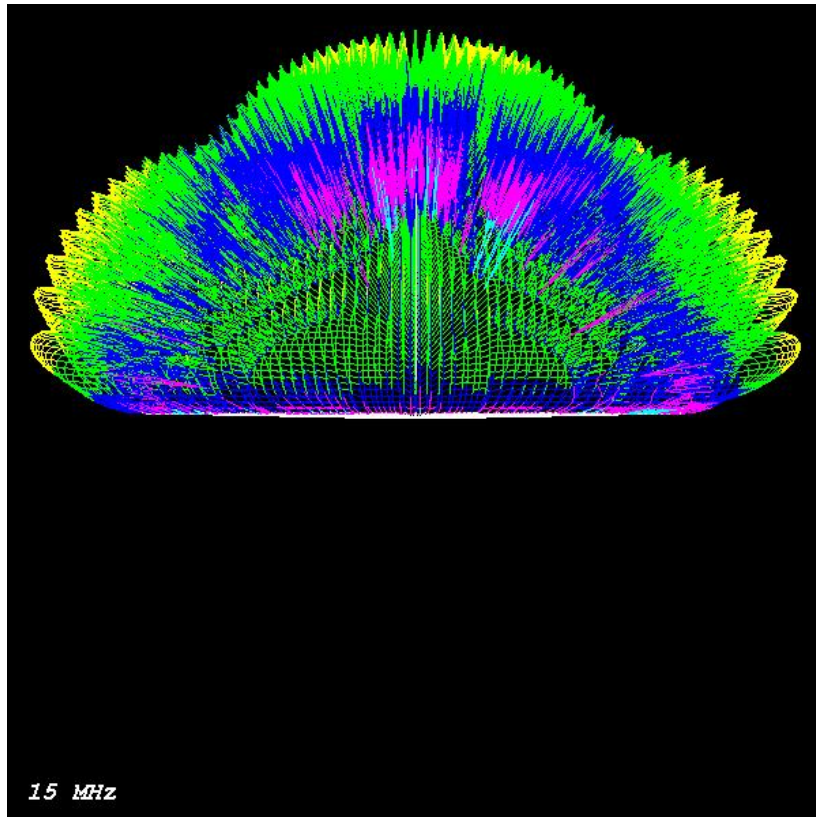
BPL  $Z_{load} = 50 + j0$   $Z_{in} = 114 + j418$   $f = 15.0$  MHz



L15M50\_15hpa

L15M50\_15hpb

BPL  $Z_{load} = 100 + j0$   $Z_{in} = 192 + j395$   $f = 15.0$  MHz

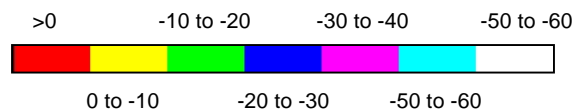
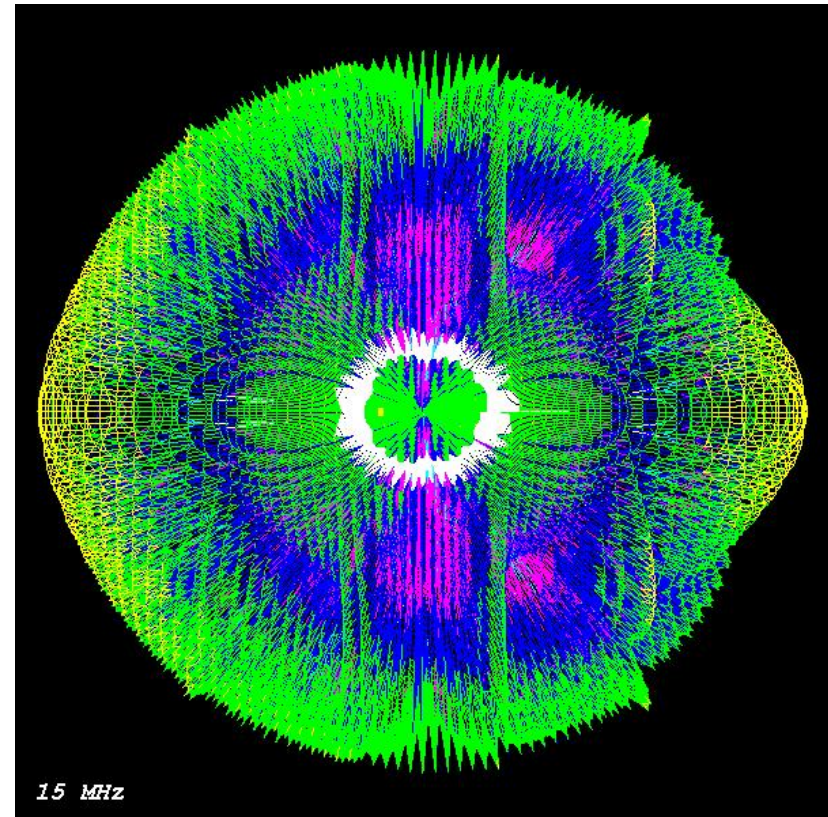
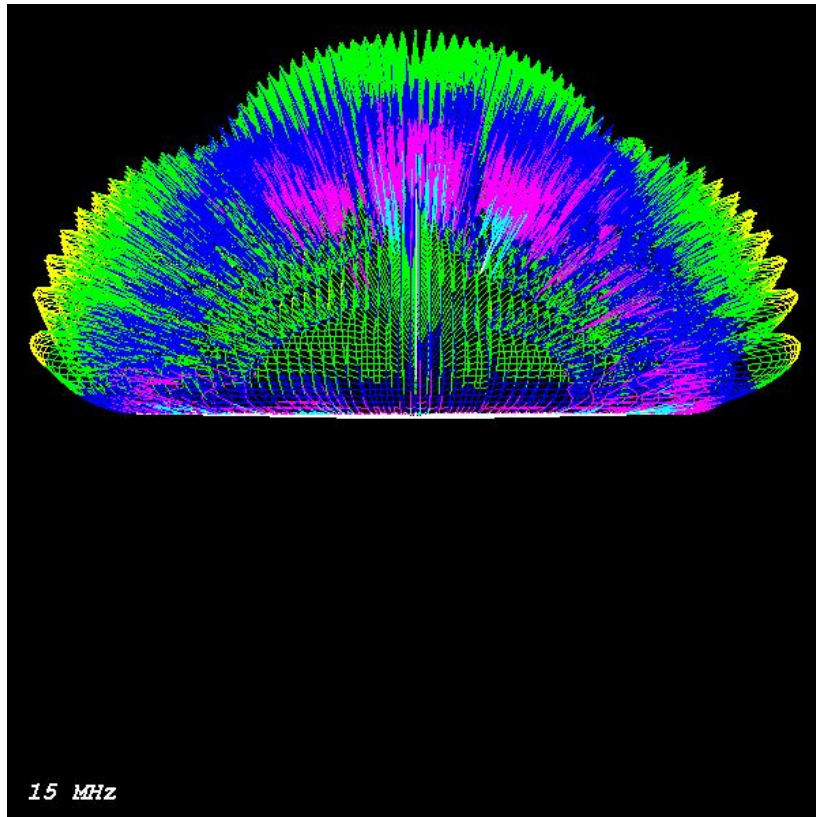


L15M100\_15hpa

L15M100\_15hpb



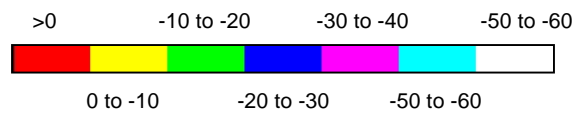
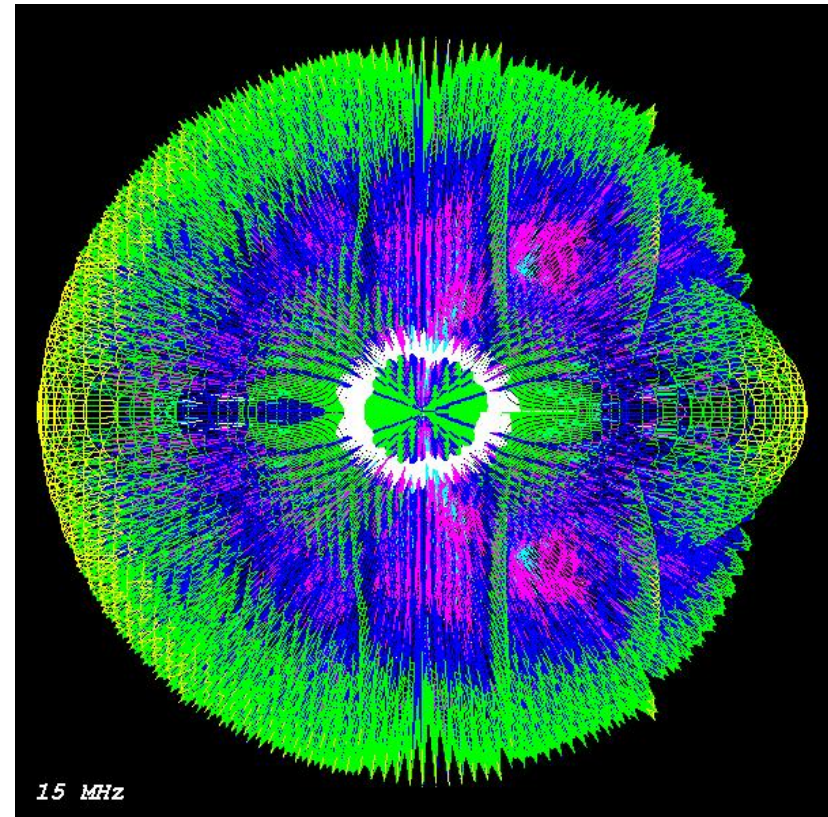
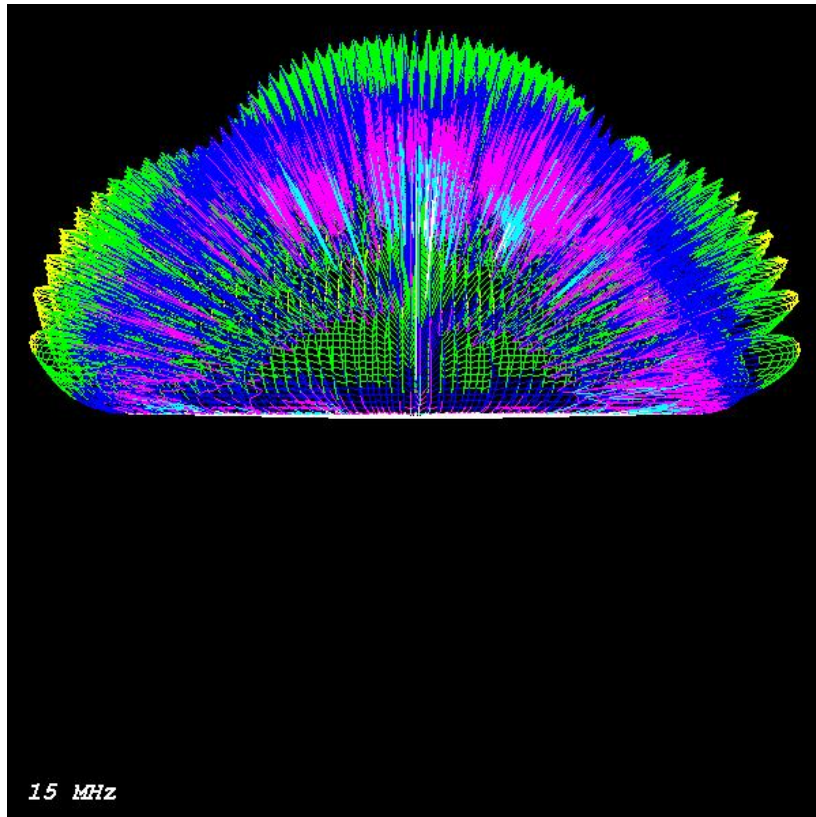
BPL  $Z_{load} = 200 + j0$   $Z_{in} = 325 + j322$   $f = 15.0$  MHz



L15M200\_15hpa

L15M200\_15hpb

BPL  $Z_{load} = 400 + j0$   $Z_{in} = 488 + j123$   $f = 15.0$  MHz

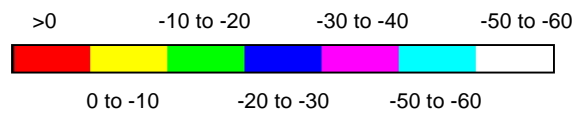
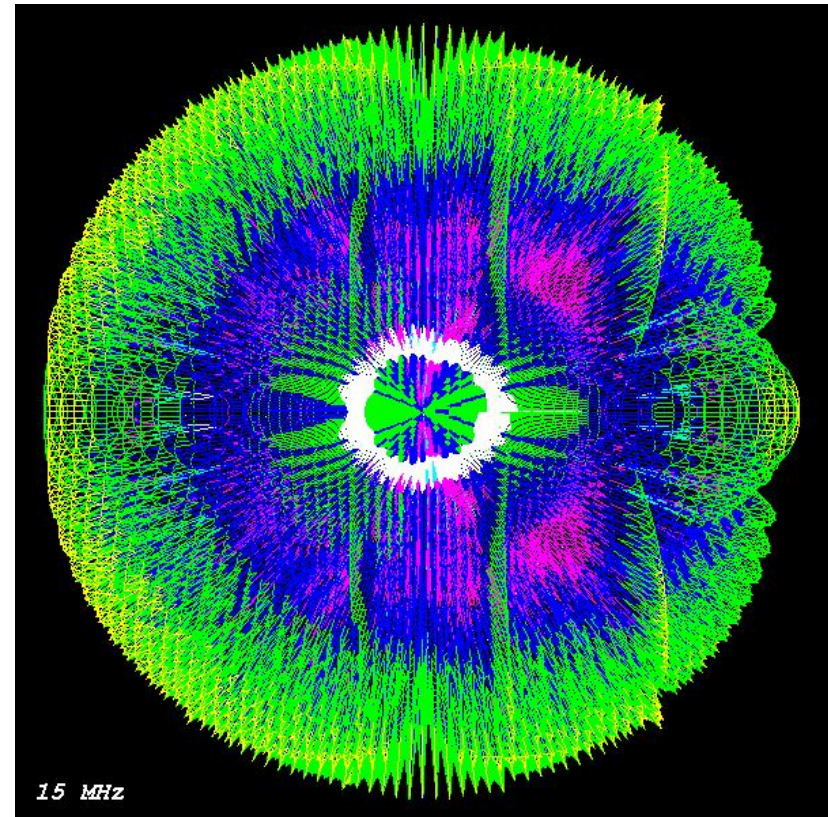
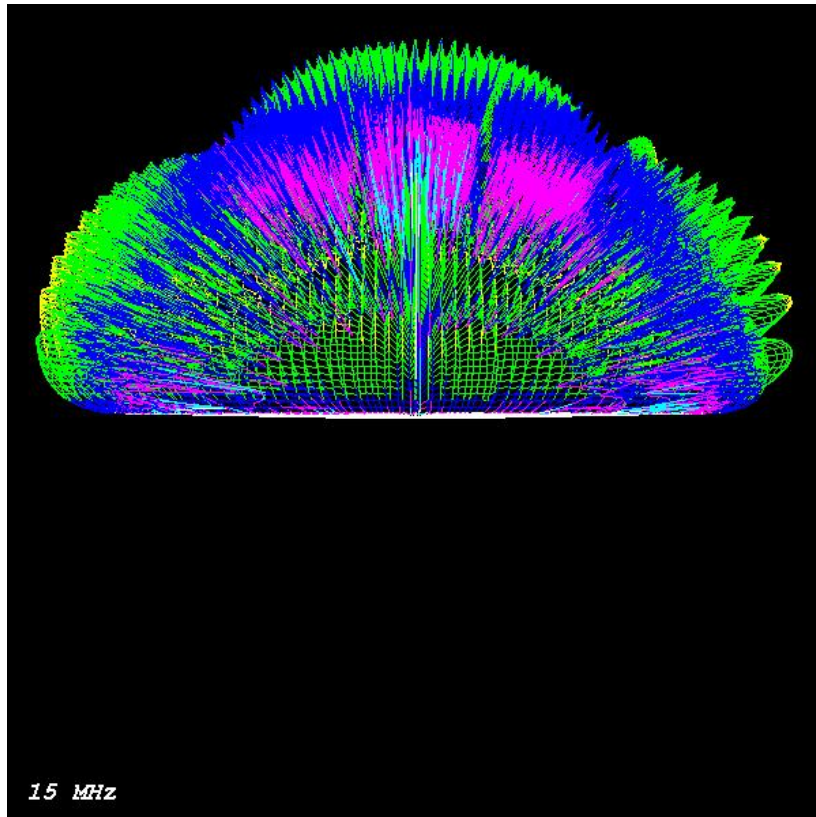


L15M400\_15hpa

L15M400\_15hpb



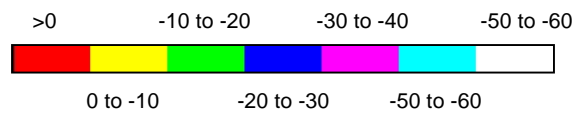
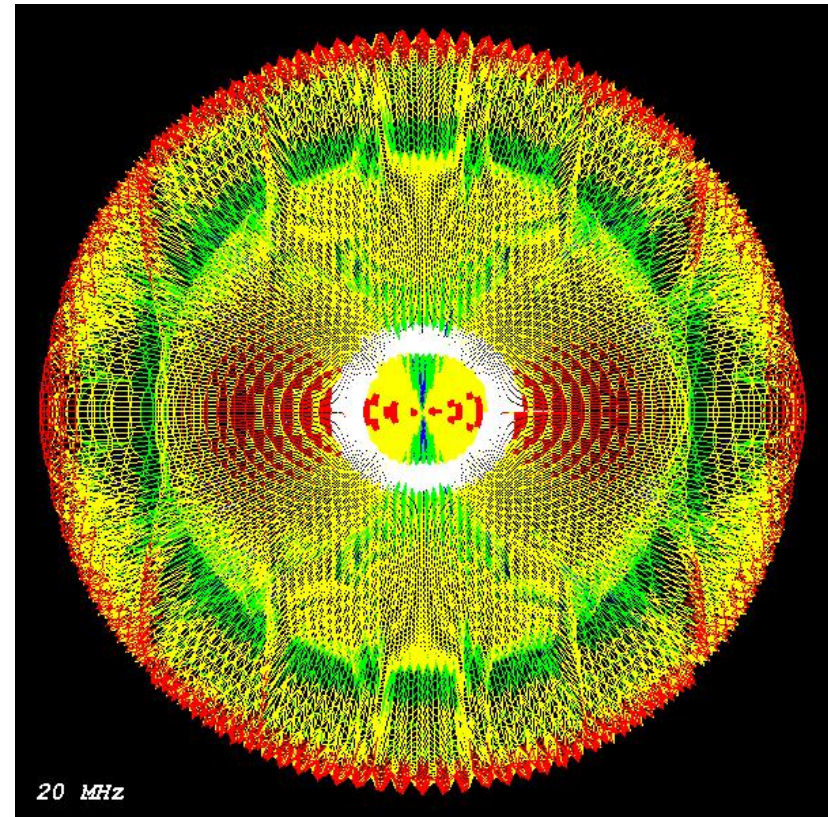
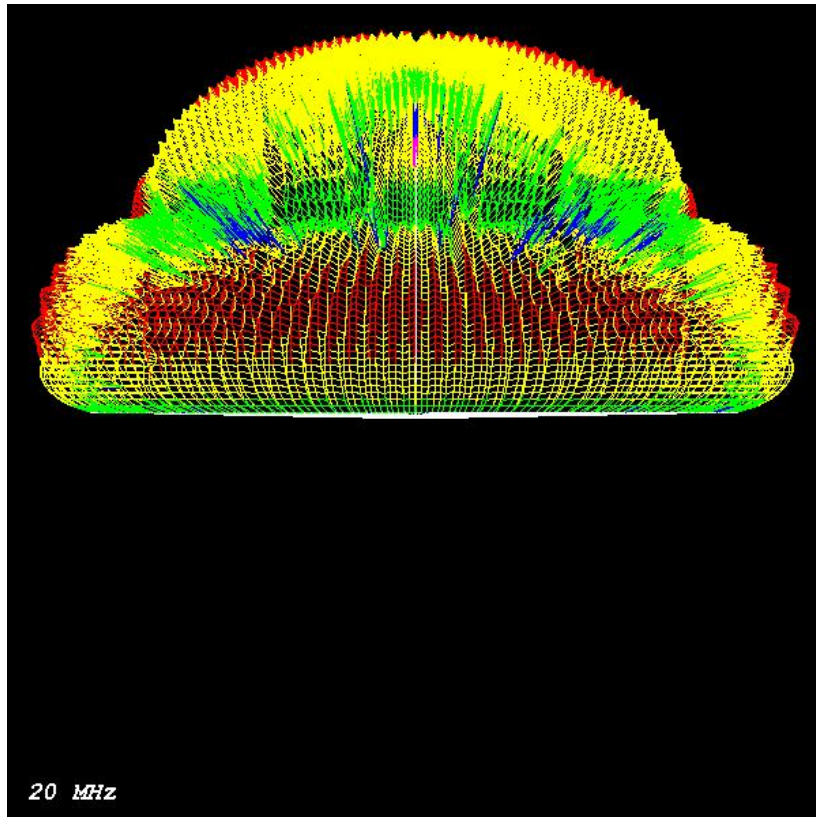
BPL  $Z_{load} = 1000 + j0$   $Z_{in} = 503 - j311$   $f = 15.0$  MHz



L15M1000\_15hpa

L15M1000\_15hpb

BPL  $Z_{load} = 6.25 + j0$   $Z_{in} = 253 - j1399$   $f = 20.0$  MHz

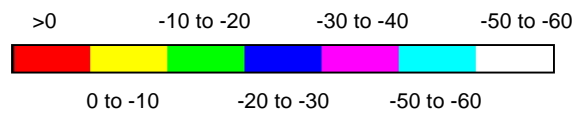
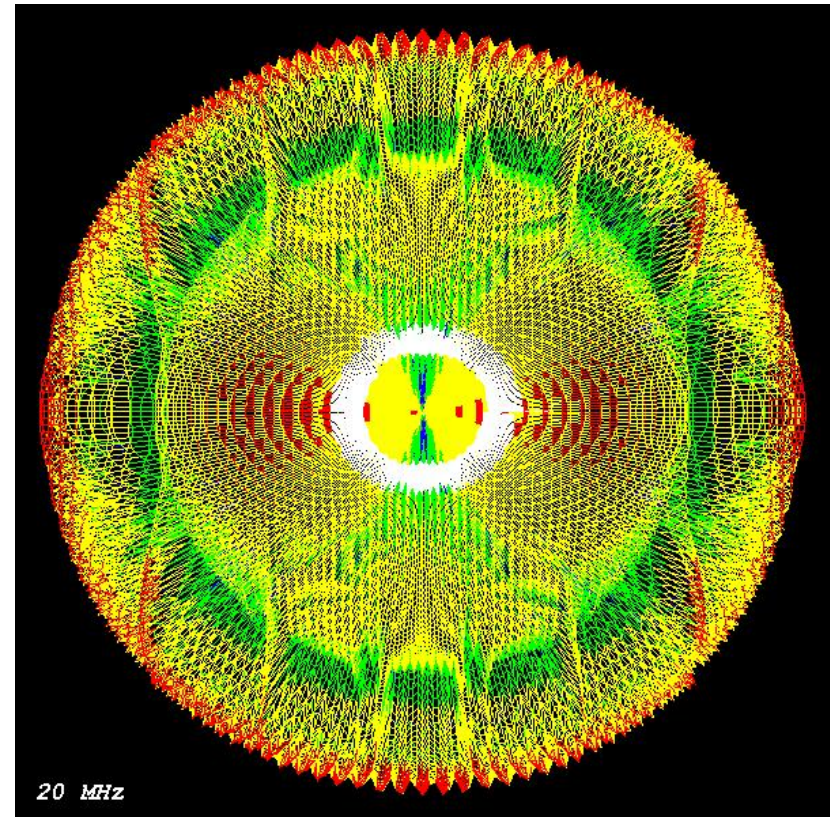
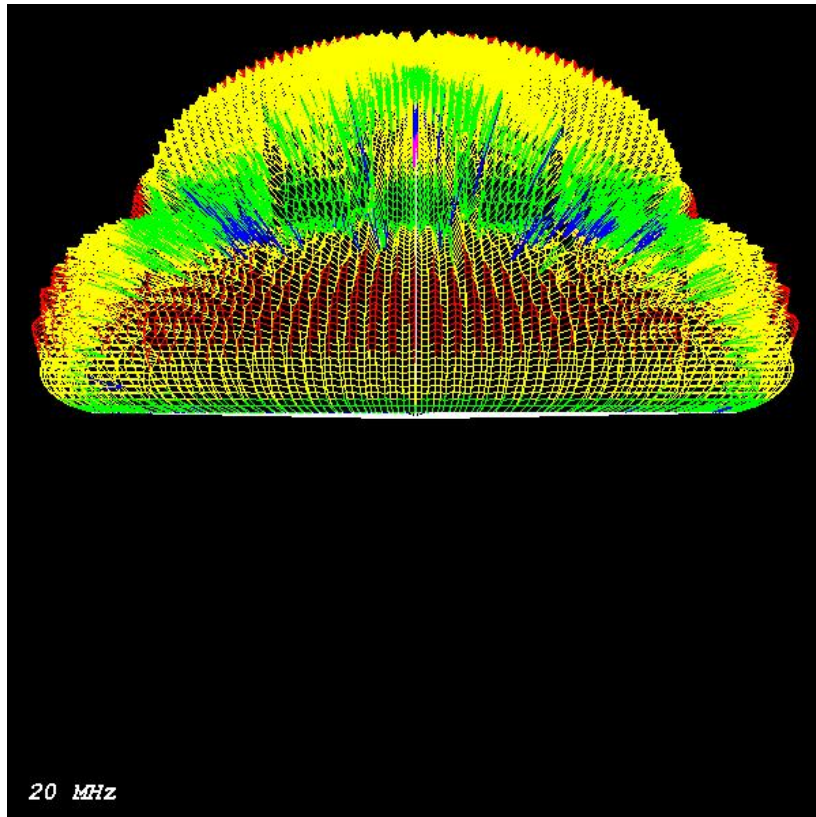


L20M6\_20hpa

L20M6\_20hpb



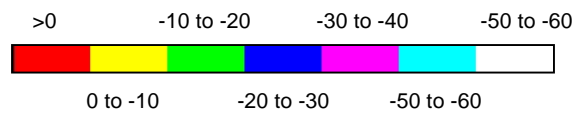
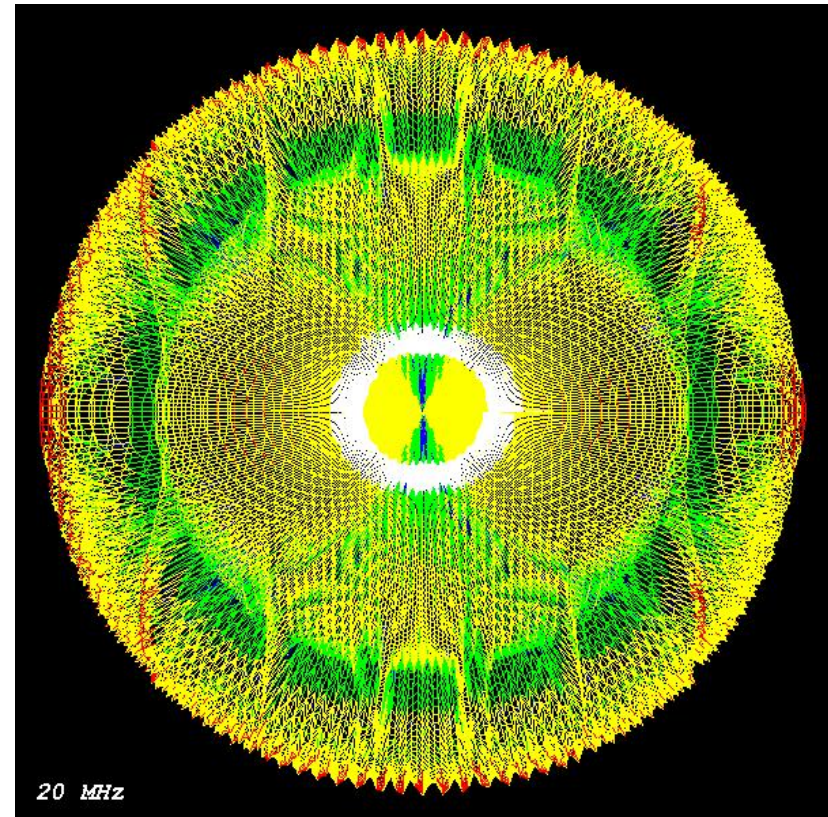
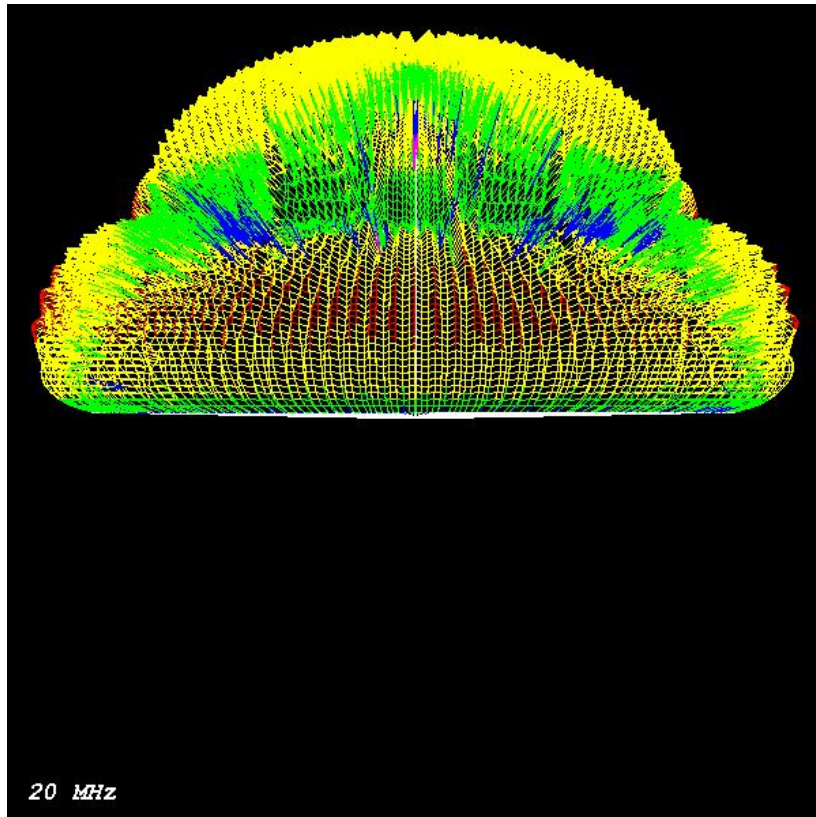
BPL  $Z_{load} = 12.5 + j0$   $Z_{in} = 293 - j1385$   $f = 20.0$  MHz



L20M12\_20hpa

L20M12\_20hpb

BPL  $Z_{load} = 25 + j0$   $Z_{in} = 368 - j1353$   $f = 20.0$  MHz

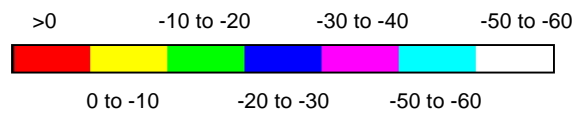
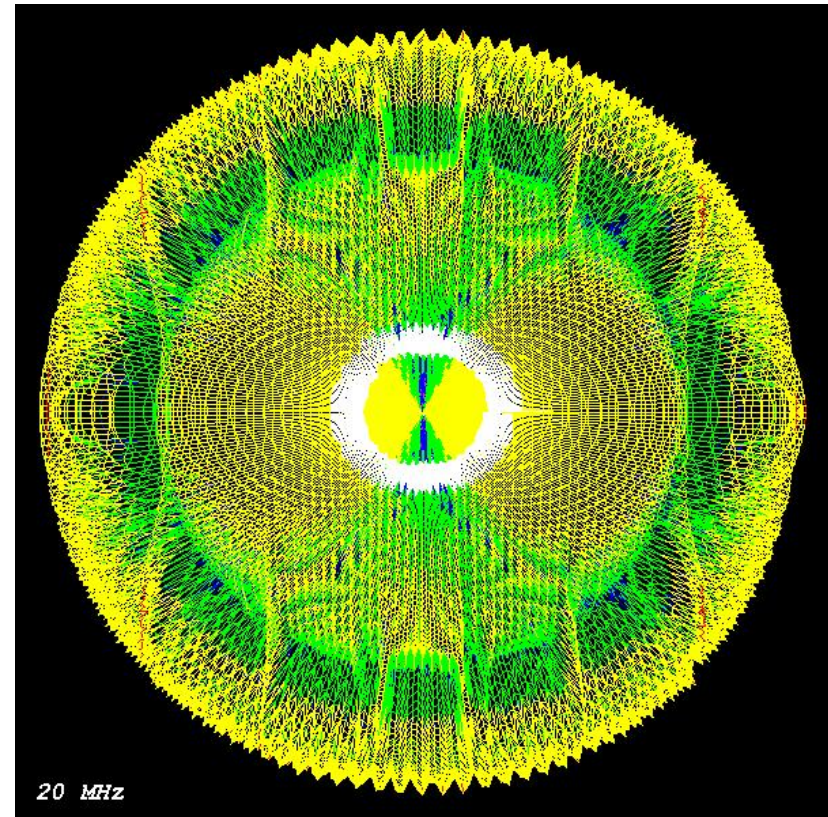
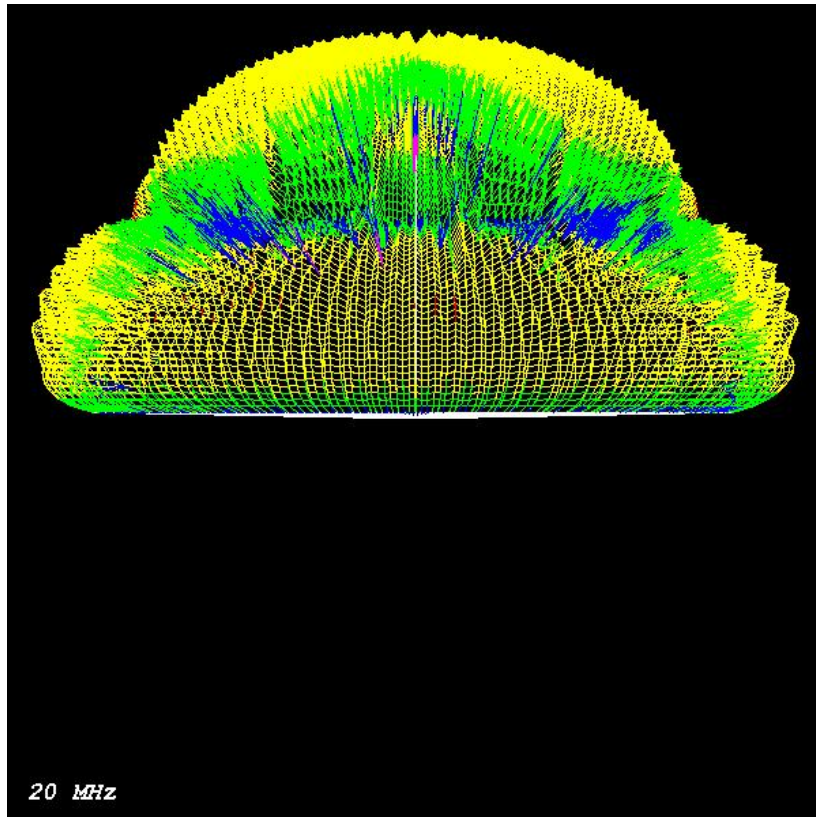


L20M25\_20hpa

L20M25\_20hpb



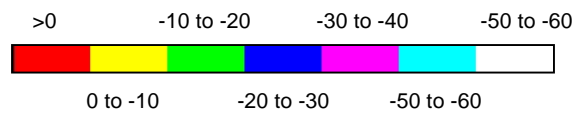
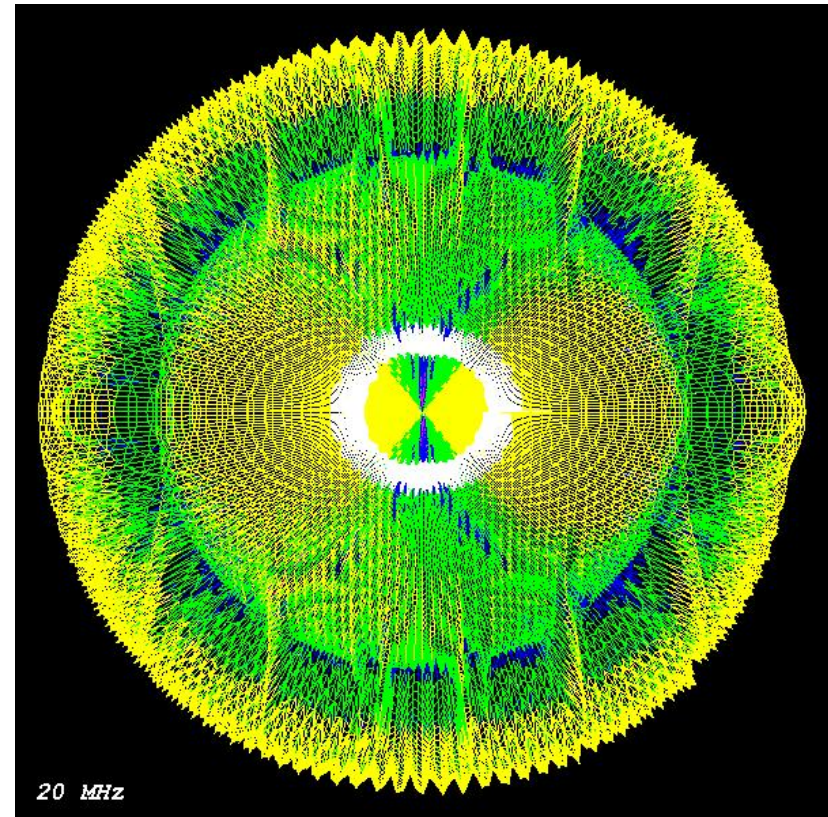
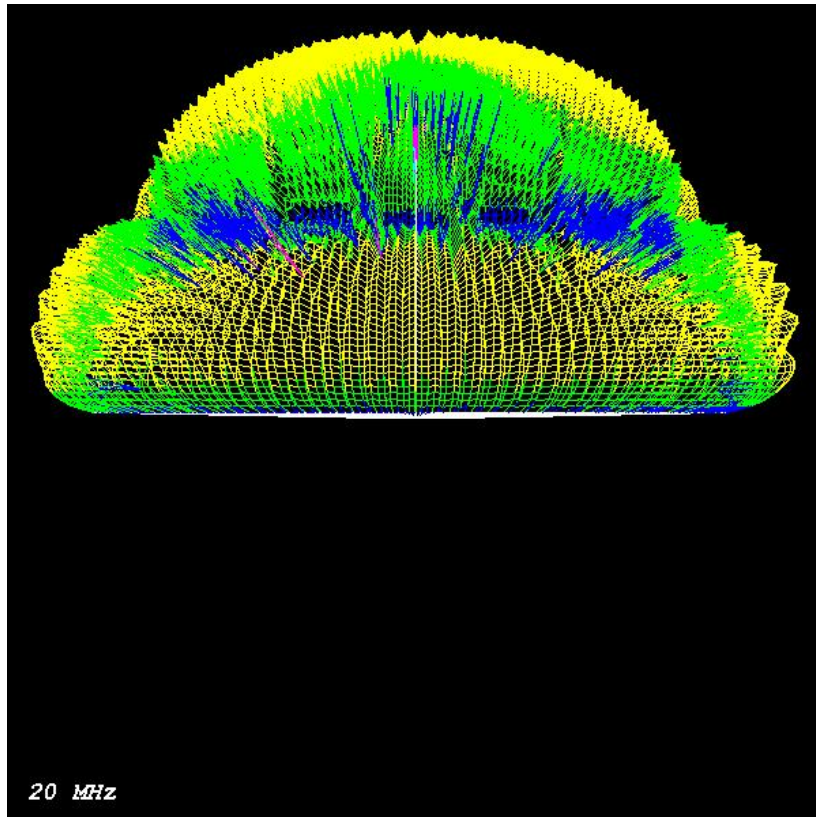
BPL  $Z_{load} = 50 + j0$   $Z_{in} = 504 - j1271$   $f = 20.0$  MHz



L20M50\_20hpa

L20M50\_20hpb

BPL  $Z_{load} = 100 + j0$   $Z_{in} = 700 - j1065$   $f = 20.0$  MHz

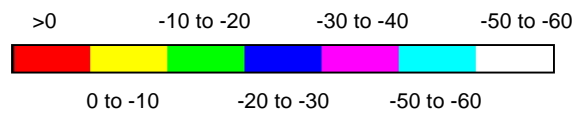
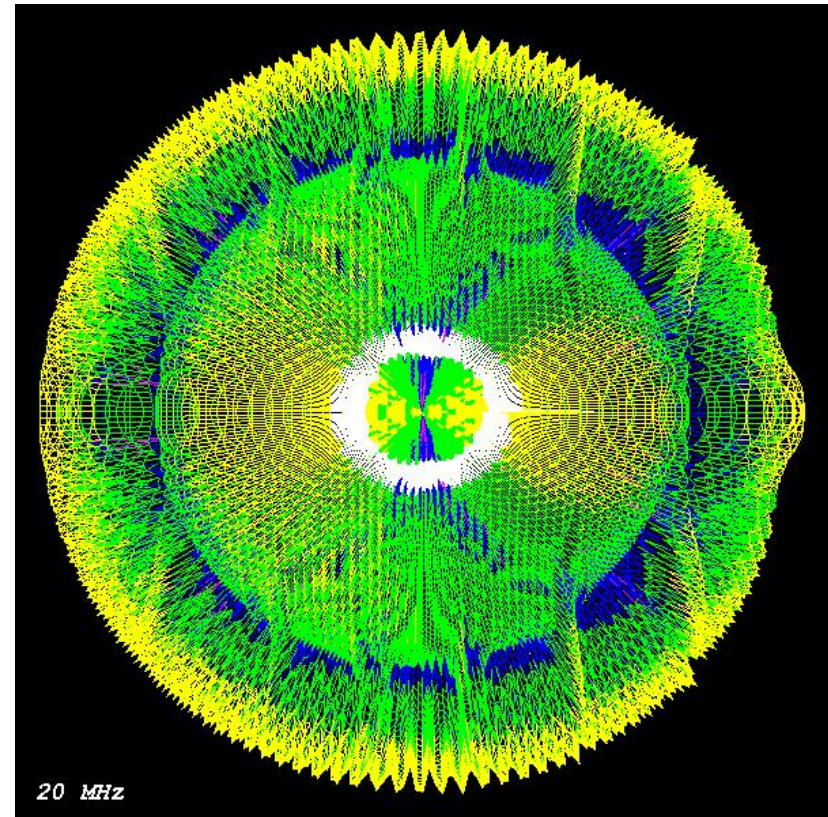
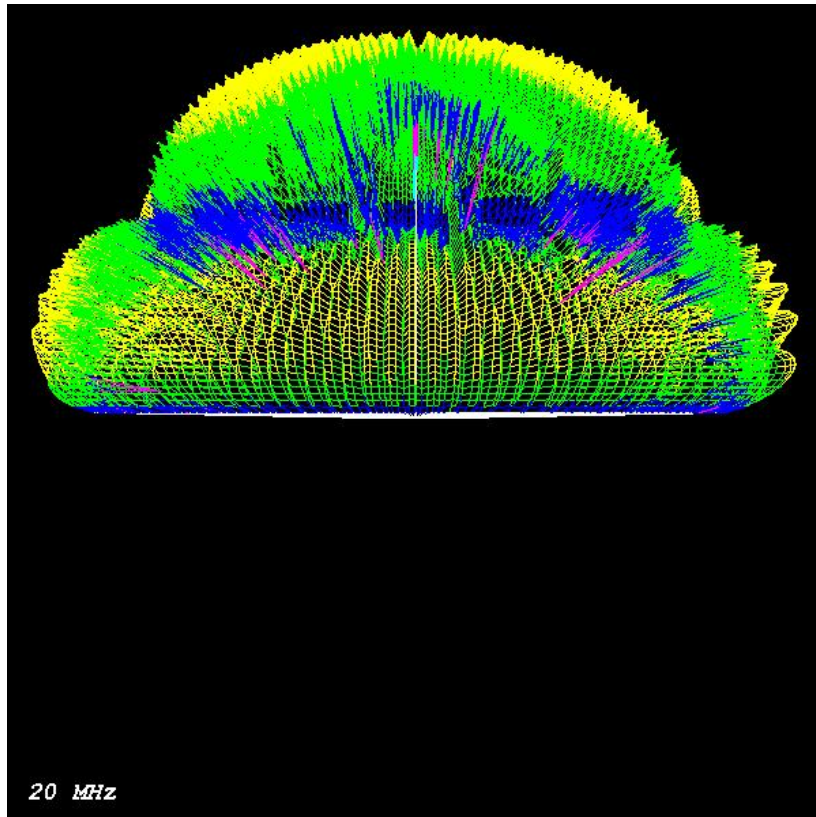


L20M100\_20hpa

L20M100\_20hpb



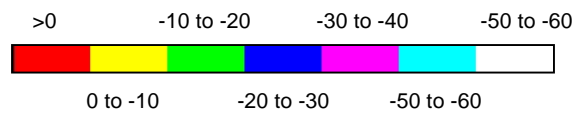
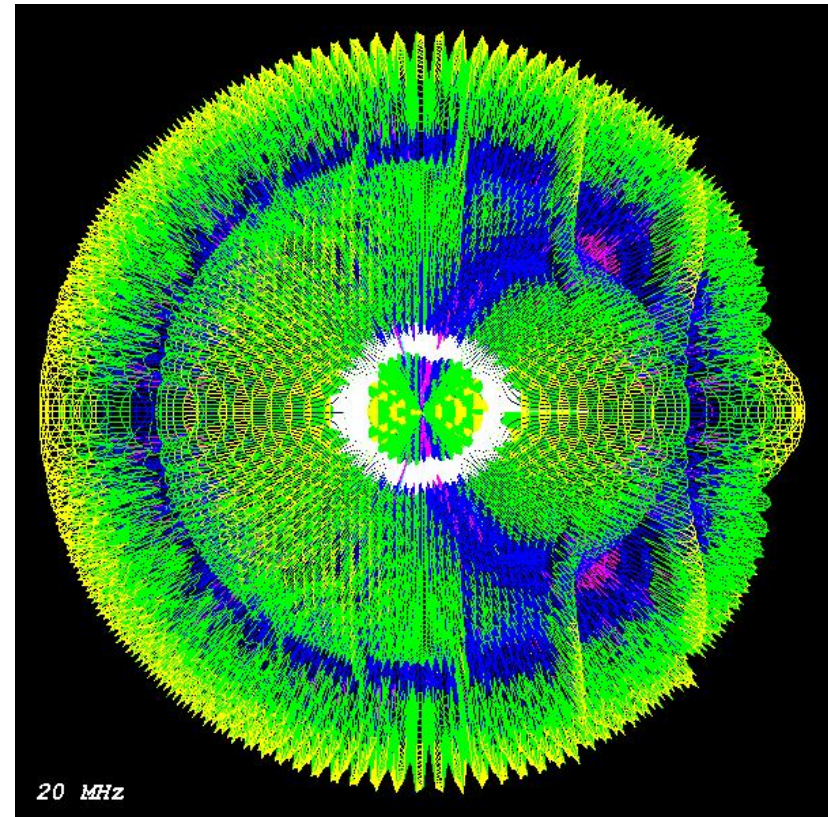
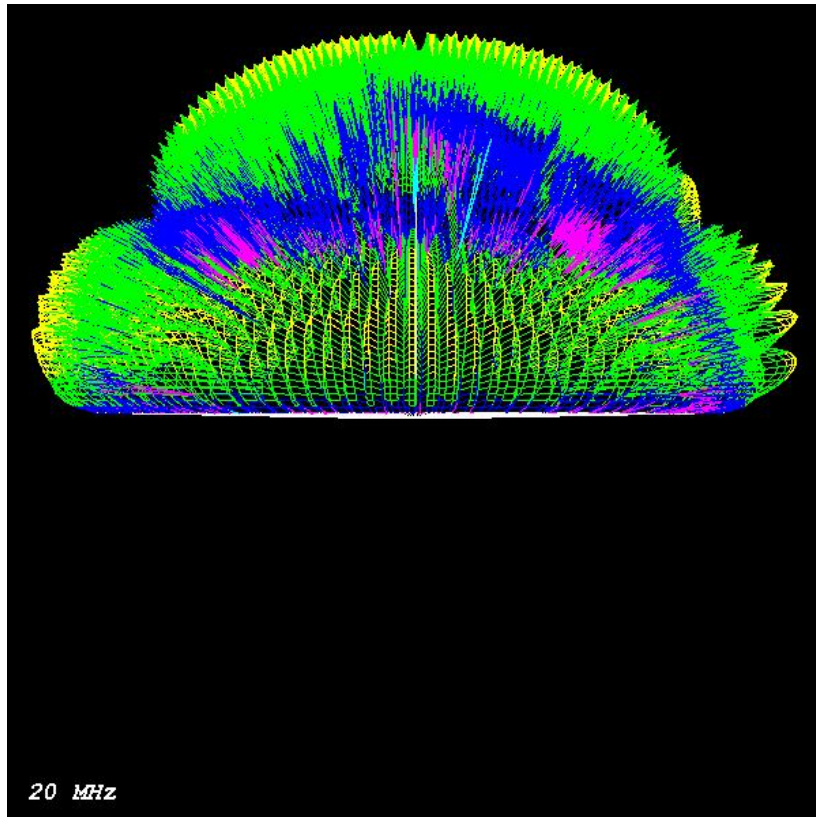
BPL  $Z_{load} = 200 + j0$   $Z_{in} = 840 - j655$   $f = 20.0$  MHz



L20M200\_20hpa

L20M200\_20hpb

BPL  $Z_{load} = 400 + j0$   $Z_{in} = 734 - j184$   $f = 20.0$  MHz

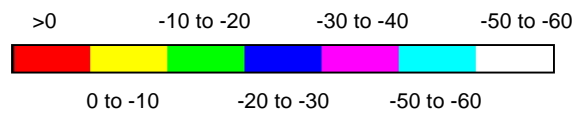
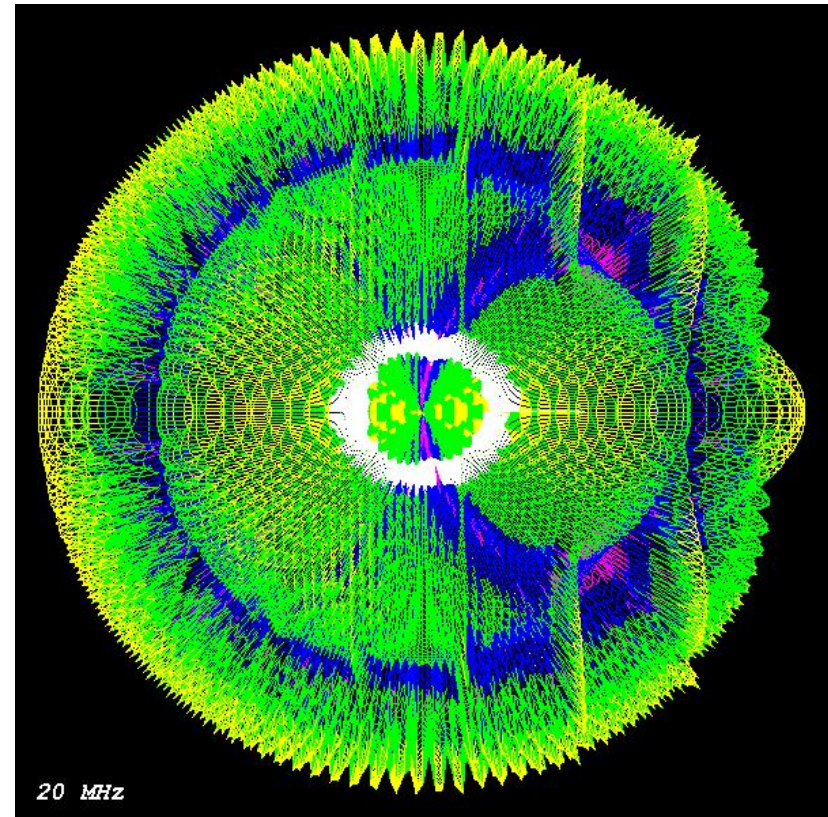
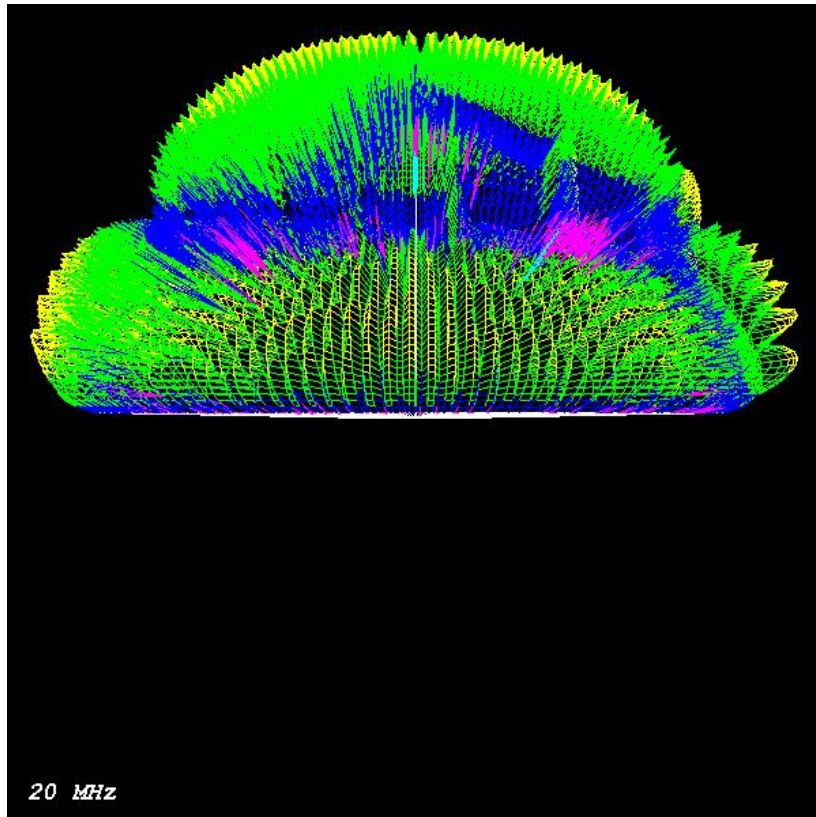


L20M400\_20hpa

L20M400\_20hpb



BPL  $Z_{load} = 1000 + j0$   $Z_{in} = 406 + j140$   $f = 20.0$  MHz



L20M1000\_20hpa

L20M1000\_20hpb